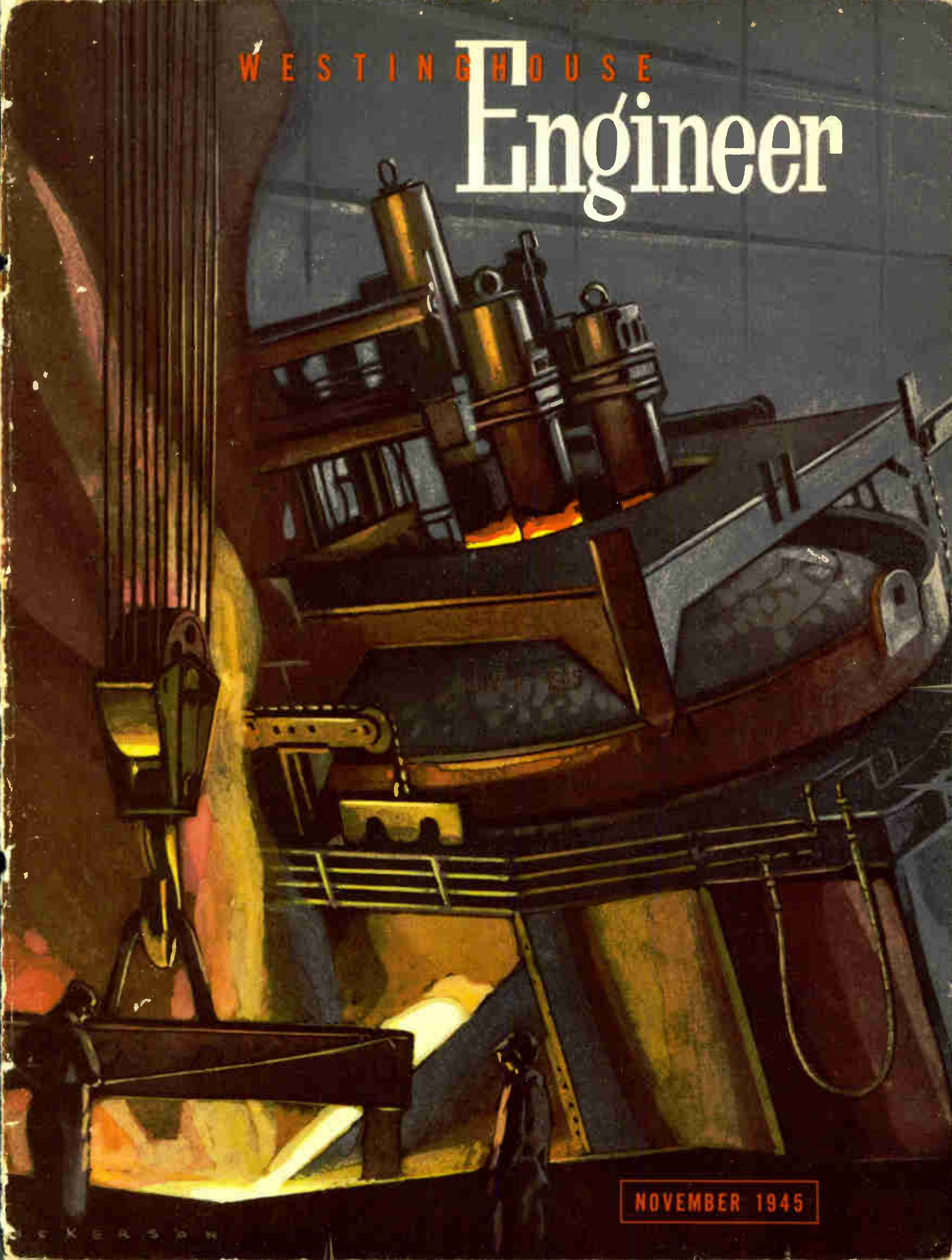
WESTINGHOUSE Engineer



NOVEMBER 1945

The Electric-Arc Furnace—Showman Extraordinary

A strong contender for the most spectacular of all man's contraptions is the electric-arc furnace. Certainly it tops any other electrical device, many of which are motionless and others that operate with little display or motion. To watch a row of arc furnaces is inevitably to be reminded of Dante's Inferno. These are giant cylindrical pots with enormous carbon stalks protruding through the dome-shaped roofs and glowing red for some distance where they enter the furnaces. Draped from the ends of the carbons to the building wall are many loops of heavy cable, indicating the association of these contrivances with things electrical. Hooded or goggled operators stand by to toss in scoopfuls of material, resulting in an angry response of ugly colored smoke from the interior. Now and then one of the furnaces lazily rolls over on its side and pours out a stream of white-hot liquid that runs, lava like, into a king-size ladle. Arc-furnace operation is, indeed, an awesome sight.

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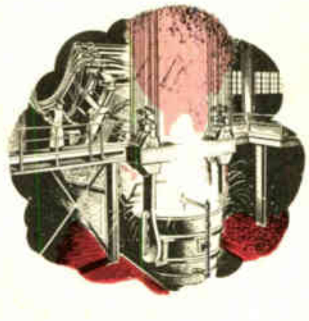

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The electric steel furnace is used for two distinct processes. In the first, the acid process, the material to be melted is charged into a furnace lined with a refractory having an acid reaction. The first action of the furnace is to melt the charge. After the charge is melted, the second action of the furnace takes place, refining the charge. During the refining, the charge in the acid furnace can be completely de-oxidized; while sulphur, if present, can be partially eliminated. The percentage of carbon can be absolutely controlled. However, the percentage of phosphorus cannot be reduced and the raw material must be low in this element if the finished product is to be free from its influence.

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In the second process, known as the basic electric process, the electric furnace is lined with a basic material (magnesite). The charge is first melted, and then treated with fluxing agents to reduce the phosphorus content. During this stage of the process, the metal is de-oxidized to a considerable extent and the carbon reduced to a low point. The slag formed by the fluxing agents is then removed and another refining slag of somewhat different nature is added. The sulphur is now reduced to as low a point as may be desired, the metal thoroughly de-oxidized, and carbon and other alloys added to bring the final composition of the steel to its predetermined value. This process permits the use of an inferior grade of scrap in the furnace charge.

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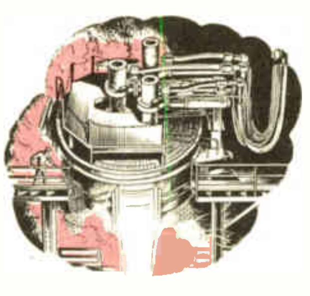
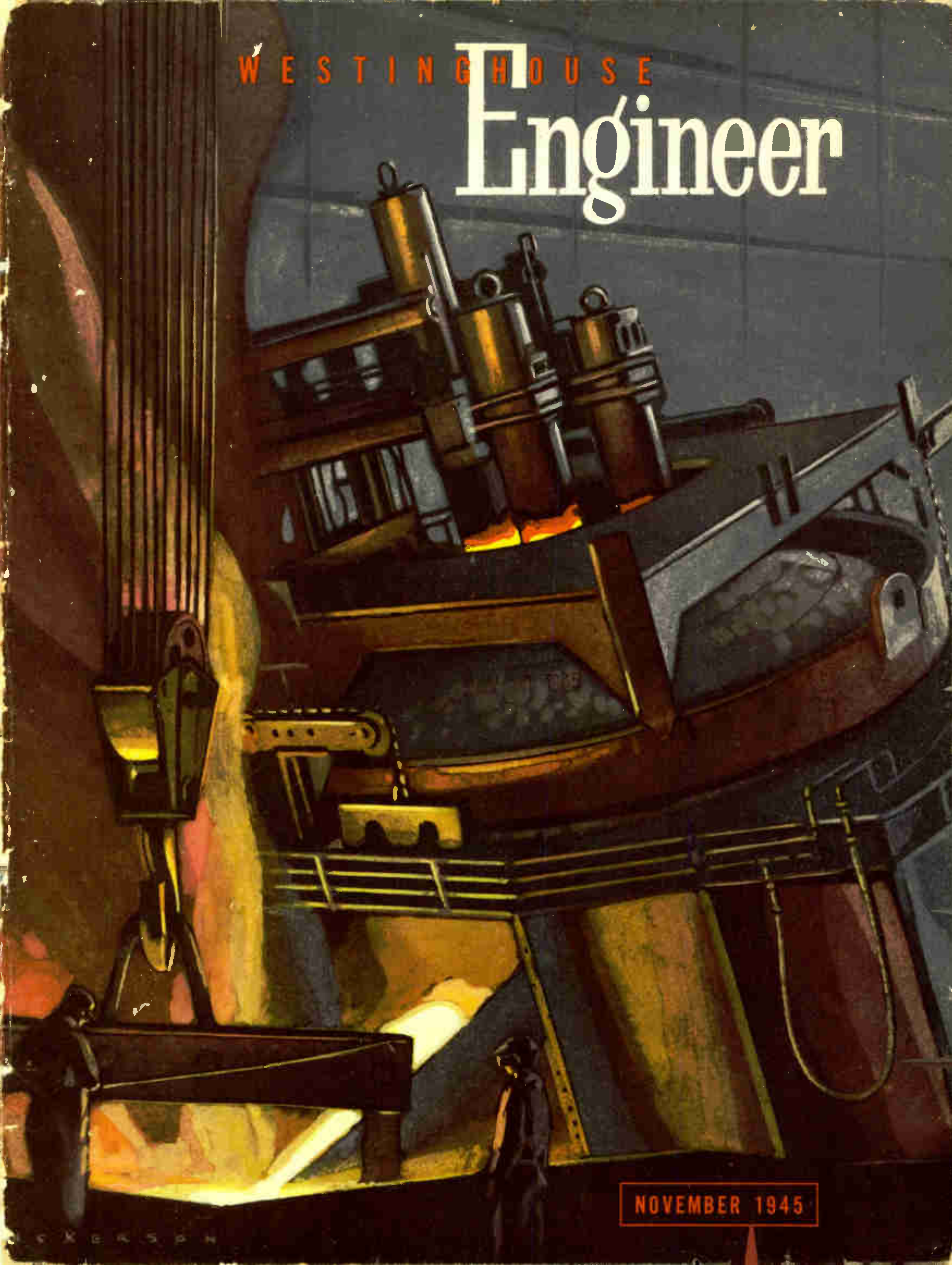
In the long-range view of steel making, electric-arc furnaces can probably be expected to rise in proportion to total steel produced. Its single important disadvantage is energy cost. About 360 kwhr are required to melt a ton of steel starting from room temperature. Nothing man can ever do will change this fundamental of nature. To this energy must be added the heat plus that required to hold the metal in a molten state during refining, plus (or minus) any required by chemical changes. This sum usually amounts to between 500 and 600 kwhr per ton, and for some special steels like stainless, up to 800 kwhr per ton. Assuming 500 kwhr even at one-half cent and an electrode cost of $1.50 per ton the cost becomes about five dollars per ton. This must be compared with 50 cents to a dollar fuel cost per ton in a blast or open-hearth furnace.



On the side of the arc furnace, however, stand many advantages. Even with remarkable improvements being made in open-hearth steel making, the electric furnace will probably continue to be unequaled in quality and consistency of product. The melting loss and alloy loss are less with the electric furnace. In the manufacture of many alloys—themselves increasing in demand—it has virtually no competition. Also arc furnaces permit small, self-contained steel-making operations, particularly where scrap is the raw material. Furthermore, through many improvements, costs of electric steel are declining steadily.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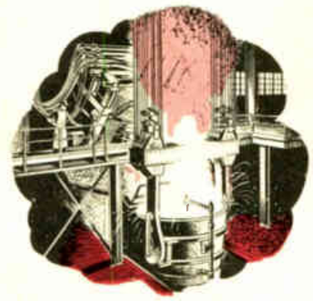

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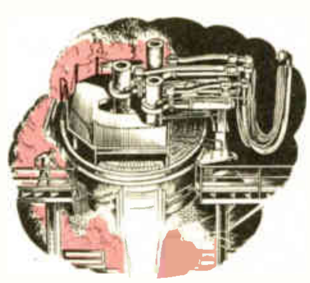

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WESTINGHOUSE Engineer

VOLUME FIVE NOVEMBER, 1945 NUMBER SIX

On the Side

The Cover—Powerful and demonstrative, the electric-arc furnace presents a picture of immense force. Yet all this force must be restrained and guided accurately. Its controls, now three in number, are discussed on page 188 in this issue.

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The Atomic-Power Project has engendered floods of words in all types of publications—a natural consequence, because of its enormous significance to every individual. Technically many fundamental facts are still restricted, the boundaries being set by the now-famous Smyth report. However, presented in this issue is an account of some of the technical aspects of this astounding venture in nuclear physics by "one who was there," Dr. E. U. Condon, Associate Director of the Westinghouse Research Laboratories. Because this is basically a new field of engineering, the editors of *Westinghouse ENGINEER* plan to discuss its fundamentals and developments in future issues. A sort of primer of nuclear physics is at present under way for an issue early in 1946.

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As devastating in the insect world as the atomic bomb is in the world of humans are the new insecticides. Westinghouse constructed for the armed services during the war twenty-two million insecticide "bombs," in which pyrethrum was the active agent. Building on this experience Westinghouse is now producing for the home front an insecticide bomb, made even more effective by the addition of small amounts of the fabulous DDT. These differ from other insecticide dispensers in that they release an aerosol—or fine mist—into the air from the pressure of an inert gas called Freon, the same gas used to create "cold" in refrigerators.

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TOMLINSON FORT
G. EDWARD PENDRAY

In This Issue

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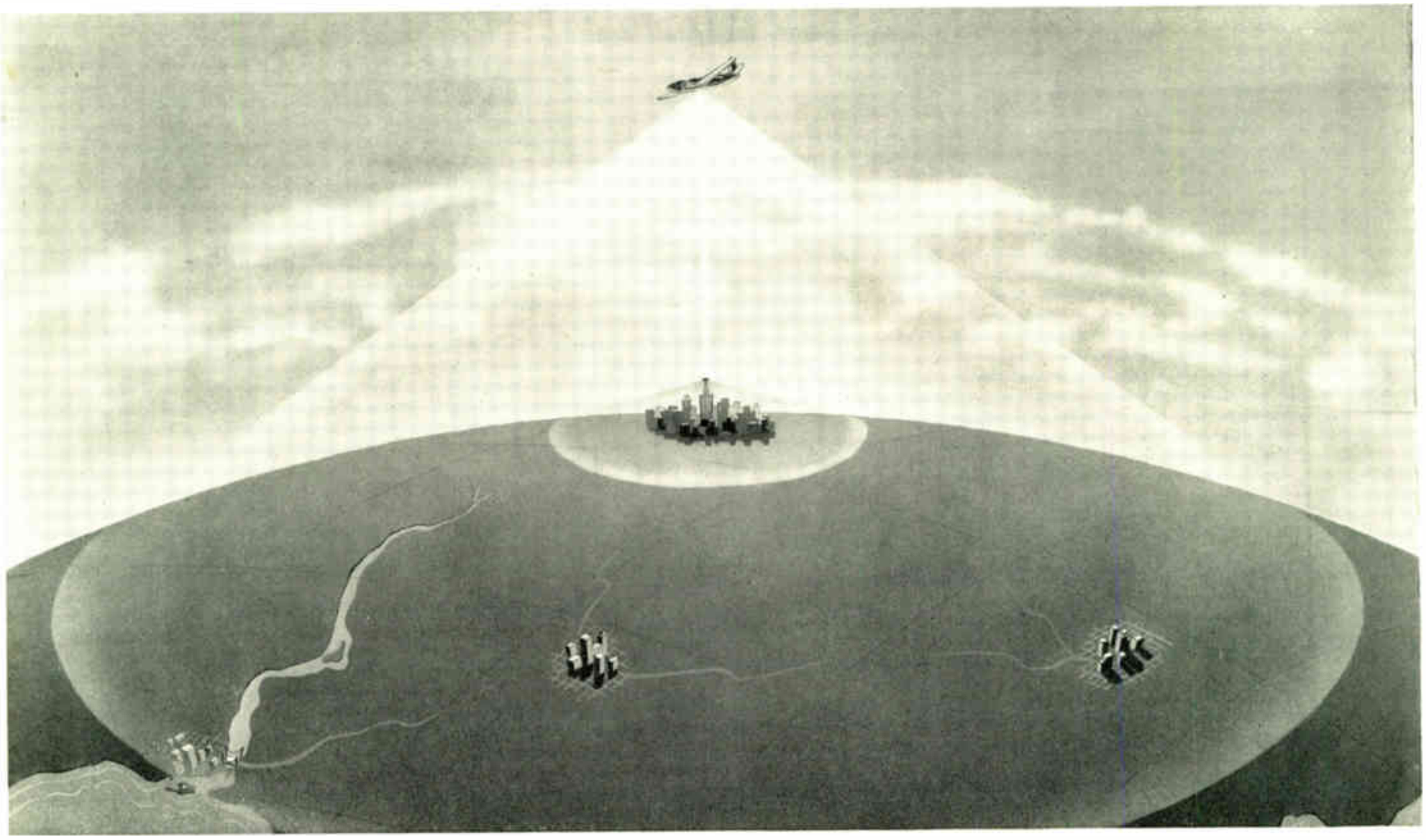


Television Programs from the Stratosphere

Because the earth's surface is curved, the man on the mountain sees farther than the man on the plain. The pilot of a high-flying aircraft sees farther still. As television and FM-broadcast waves follow line-of-sight laws, the ideal location for such stations would be far above the clouds in the stratosphere. Stratovision, by utilizing high-flying aircraft to carry low-powered transmitters into the stratosphere, makes this ideal not only possible but also commercially practical. This new conception of television and FM broadcasting is an outstanding step forward, one that hastens by many years the development of national coverage and chain broadcasting from any point in the country.

C. E. Nobles
Industrial Electronics Division
Westinghouse Electric Corporation

A system of rebroadcasting television and FM programs from airplanes flying six miles or more above the earth may seem like a startling conception today. But the practical aspects of the Stratovision system, both from the engineering and the economic viewpoints, promise to make it the commonplace method of the future. Today black-and-white television and FM have advanced technically so that excellent service is available over short distances. High-definition color television has proved its practicability, and provisions for handling this type of program must be considered in any long-term plan for expanding television service. Before Stratovision, however, many stumbling blocks have prevented the expansion of television and FM on a nationwide scale. These stumbling blocks have been both technical and financial.

Television and FM stations have a much smaller service area than a broadcasting station requiring a similar investment. The programs reach fewer people, at a higher cost per person. Little can be accomplished on the technical side to increase this service area for stations located on the ground because of the nature of television and FM waves. Relaying systems have been extremely inadequate or astronomically expensive. On the financial side, this means that a much greater investment would be needed to expand television and FM than was necessary for ordinary broadcasting. Program expenses, too, mount rapidly with television. The actors must be costumed, scenery must be provided, long rehearsals are necessary to avoid the scripts so evident in the actors' hands in the ordinary broadcasting studio. Consequently each program must be presented to a large audience, to make it profitable to the advertiser who, after all, pays the bills. For years, technical development and economic expansion worked at cross-purposes. With the Stratovision system, however, the requirements of both can be satisfied.

Obstacles to Large-Area Coverage

Increasing power extends the coverage of standard and short-wave broadcasting stations. This method, however, does not work with the ultra-high frequencies used by television and FM stations for the waves travel in different ways.

The ground wave shown in Fig. 1 provides an intense coverage of the areas adjacent to the station. The sky wave is reflected from the Heaviside layer of ionized particles 50 to 60 miles above the earth and extending to the limits of the atmosphere. Receivers close to the transmitting station receive both the ground wave and the sky wave. Receivers at a distance receive the sky wave only. However, because the ground wave by refraction follows the curvature of the earth to some extent, and the sky wave will "bounce" back and forth between the Heaviside layer and the earth, it is possible for receiving antennas beyond the horizon to receive a signal from a short-wave or standard-broadcast transmitter. Consequently, the greater the strength of the signal, the greater the area covered.

However, at the ultra-high frequencies, the radiated waves behave differently, as Fig. 2 indicates. There is no appreciable curvature to the ground wave, and ultra-high frequencies are not reflected by the Heaviside layer. The range of television and FM broadcasts is, therefore, limited to line-of-sight distances. No increase in power appreciably increases the range beyond the line-of-sight range of the station. The only way to increase the range of an ultra-high frequency station is to raise the antenna so that a larger portion of the earth's surface comes within the line-of-sight distance from the antenna. Hence the tendency is to locate television stations on tall buildings or hills.

The maximum service range of a high-powered television or FM station, even with a favorable antenna location, is limited to about 50 miles. At present, because of the problem of developing tubes that operate at the ultra-high frequencies, there is no satisfactory way of obtaining the amount of power necessary to radiate high-definition color television waves even 50 miles from the station. At the present stage of power-tube development, power of the order of five kw is attainable in the frequency range used for broadcasting color television. However, 50 kw would be necessary for coverage of a 50-mile range from even as high a location as the Chrysler Building in New York City. Oddly enough, power requirements decrease markedly as the antenna is raised higher above the ground level while the same field strength is maintained even with the increased coverage.

Raise the Antenna

The transmission range increases with antenna height. Within practical limits, the higher the antenna the better, as shown by Fig. 3 and the illustration on p. 162. Although higher altitudes would give greater coverage, the Stratovision system proposes to employ aircraft flying at an altitude of 30 000 feet, since statistics covering many types of aircraft operating at that altitude have been secured during the war.

Two factors make it possible to cover a larger area with a lower powered transmitter when the antenna is raised into the stratosphere. Because of the curvature of the earth, a greater area comes within the line-of-sight distance from the antenna. However, a second, and more complex factor also must be considered. That is the presence of a reflected wave at the receiving antenna. This wave is reflected by the ground towards the receiving antenna where it is received in the same manner as the direct wave. However, because of the reflective characteristics of the earth, it is reversed in phase during reflection. Consequently, if the path distance of the direct wave and the reflected wave are essentially the same, the two waves will tend to cancel at the receiving antenna. It is also possible to obtain a condition in which such a cancellation occurs when the length of one path differs from the length of the other by one wavelength. However, this can be offset on nearby installations, Fig. 4(a), by moving the receiving antenna a few feet to secure optimum receiving conditions. However, on longer ranges, when the lengths of both paths are almost identical, moving the antenna does not affect the difference in the paths of the two waves. Consequently a practical limit of reception is the point at which the paths of both waves are approximately equal, although the receiving antenna may be within the line of sight of the transmitting antenna.

The paths of the direct and the reflected waves tend to approach an equal length as the receiving antenna is moved farther from the transmitting antenna. The farther apart the two antennas are located, the more closely the distance travelled by the direct wave approaches the distance travelled by the reflected wave. When these two distances are the same, the signals almost cancel (because of the 180-degree reversal by reflection) and only a small percentage of the direct-wave field strength is obtained at the receiving antenna. This point determines the maximum range of the transmitter.

The higher the antenna, the greater the distance before this cancellation takes place. This is shown in Fig. 4(b). An approximate method of calculating maximum range due to this effect is expressed in the following mathematical formula:

$$E = 88\frac{\sqrt{W}\,h_t h_r}{\lambda d^2}$$

where E = Field strength at the receiving antenna in millivolts per meter, W = Watts of power radiated by the transmitting antenna, h_t = Height of transmitting antenna (meters),

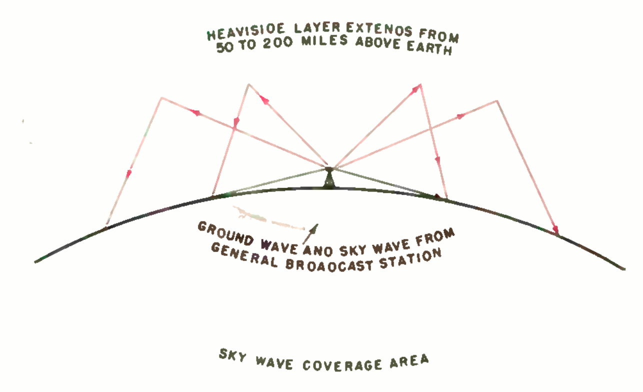


Fig. 1—Reflections from the Heaviside layer give broadcast-frequency coverage far beyond the visible horizon.

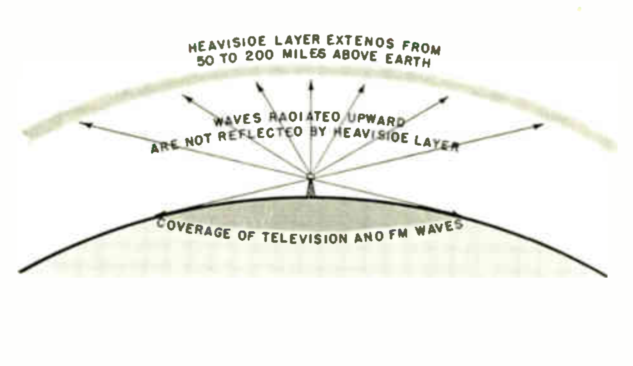


Fig. 2—The Heaviside layer does not reflect waves in the television band of frequencies. Hence reception of an earth-bound station is limited mainly to line-of-sight areas.

h_r = Height of receiving antenna (meters), d = Distance between the two antennas on the ground (meters), λ = Wavelength of the transmitted wave (meters). This formula can also be written:

$$W = \frac{1}{h_t^2} \times \left(\frac{E\lambda d^2}{88 h_r}\right)^2$$

Because the desired field strength (E) at the receiving antenna, the fixed wavelength (λ), the given distance (d) and the fixed receiving antenna height (h_r) are constants, the watts necessary for coverage at the receiving antenna vary inversely as the square of the height of the transmitting antenna. Thus, the transmitted power can be decreased greatly as the antenna is raised without affecting the field strength at the receiving antenna. A 1000-watt transmitter located 30 000 feet in the air can provide a greater field strength at a receiving antenna than is possible with a 50 000-watt transmitter located near the ground. And, of course, with this decrease in required power, the high location of the antenna also brings a larger service area within the line-of-sight distance of the transmitting antenna.

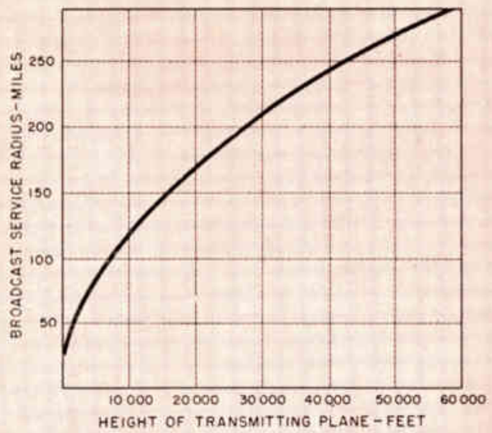


Fig. 3—As antenna height increases the horizon recedes.

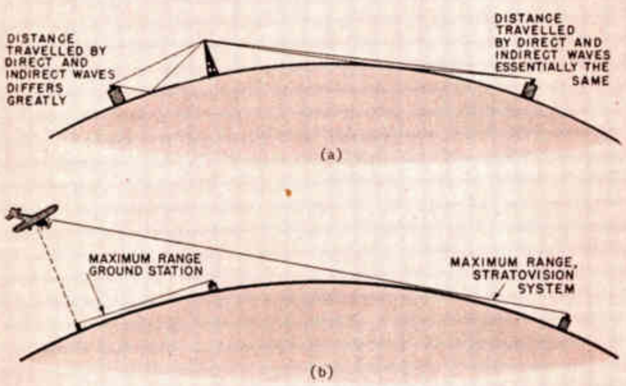


Fig. 4—(a) Earth-reflected waves from low-height antennas may interfere with the direct waves and create an "echo" or ghosting effect. (b) The higher the antenna the less pronounced the ghost effect and thus the greater the coverage.

Chain Programs

The high cost of production requires that television programs be broadcast to a tremendous number of homes in order to keep the per-receiver cost low. With ordinary broadcasting, the procedure of increasing the size of the audience is simple. The relatively narrow band of audio frequencies required for standard broadcasting can be carried on ordinary telephone lines. This method is employed by the present-day broadcasting chains. However, in television, and to a lesser extent in FM, this system is not practical because of the wide range of signal frequencies required. Two systems of connecting television stations into chains had been proposed and were being considered before Stratovision. Both of these systems were astronomically expensive and would take years to establish. Neither was capable of handling the signal frequencies required by the new high-definition color television because of distortion inherent in them.

One of these proposals is to provide a coaxial cable of special characteristics to link together the various television stations, about as shown in Fig. 5. The installed cost of such a cable is approximately $3.00 a foot. At this rate, the cable installation above would cost $100 000 000 for just a single chain across the country. Repeater amplifier stations, located approximately every five miles along this cable would also be necessary, making the installation cost still greater, and adding terrific cost for operation and maintenance. Further, it has been estimated that it would take approximately five years to install such a cable, thus slowing down television's development by that time. Such a cable, at $100 000 000 would be merely an East-West link, with a few feeders to nearby points from the main cable. The cost of nationwide coverage would be even higher.

A second proposal is to provide radio-relay stations across the country. Because the range of these stations would be only about 35 miles, over 100 such relay stations would be required to provide a direct hookup between the east and west coasts. Hundreds more would be required to provide nationwide coverage. The proposed path of these relay networks is shown in Fig. 6. Such a chain would take years to construct, and the cost would have to be borne by the operators of the television and FM broadcasting stations, in addition to the expense of maintaining and operating their own stations and programs.

Also, the number of times a program is relayed affects the quality of the program, for each relaying point tends to distort the signals. Therefore, the fewer the number of relay points, the better the quality of the program.

The Stratovision System

The Stratovision system proposes to relay the programs between the same aircraft that broadcast the programs. Relaying between the aircraft flying high in the stratosphere is relatively simple. The line-of-sight distance between two aircraft flying at 30 000 feet is over 400 miles and their heights minimize the effects of ground reflections. Consequently, eight such aircraft, strategically located between New York and San Francisco could provide effective transcontinental relaying. Also, inasmuch as only eight relaying operations are required, instead of over 100 for radio relaying and 600 for coaxial-cable relaying, less relaying distortion will be present and the quality of the programs would be superior.

The number of stations required to cover the country with television and FM programs is the same as the number required to conduct the relaying. Thus one active airplane in the air over a given area will not only service that area, but will also provide relaying facilities for the nationwide network. As shown in Fig. 7, eight airplanes can provide complete New York-to-Los Angeles coverage, and will, at the same time, provide a cross-country relaying system. Six additional aircraft will provide a coverage of over 78 percent of the country's population. And these aircraft, because of the low-powered transmitters required at high altitudes, will not only serve their area with one program, but also can serve it with four television and five FM programs, and handle all the relaying operations necessary in the network. In other words, each broadcasting airplane is not one broadcast station but nine stations.

Why Use Airplanes?

In the early development of the Stratovision system, captive balloons or dirigibles were considered. However, the lifting power of any gas-filled aircraft at the altitudes desired is low because of the rarification of the air. Captive balloons, unless tremendously large, could not lift the weight of their cables and they would also swing over wide areas by the wind. No dirigible has yet been built with a ceiling of 30 000 feet, capable of providing appreciable lift.

The problem, on the other hand, is a relatively simple one for heavier-than-air craft. Like most other aircraft manufacturers, the wartime experience of the Glenn L. Martin Company, which is developing the aircraft necessary, has been a struggle to build larger aircraft with greater pay-load capacity, which would go farther and faster than heretofore. The problem of designing the Stratovision aircraft was, on the contrary, a matter of creating an aircraft which would go nowhere slowly. A practical design was rapidly produced. This aircraft is a large, low-wing-load transport plane with a speed capable of maintaining the aircraft in a position over a city despite any winds encountered at 30 000 feet.

Under present plans, four aircraft at each relaying point will be required to provide for a 24-hour period of operation. Each aircraft will fly an eight-hour shift and two aircraft will be in the air at all times. One would be transmitting while the other would be a stand-by plane in case it was necessary for the first one to make an emergency landing. This will provide uninterrupted service for the area being covered, and also provide uninterrupted relaying for the network. The flight time of the aircraft would be staggered, so that an airplane would take off and descend every four hours, as the schedule of Fig. 8 shows. This would require three aircraft in active service at all times. The fourth would be grounded for repairs and maintenance.

These aircraft would be equipped with hot-air de-icers, blind navigation equipment, blind-landing equipment and a pressurized cabin to enable them to operate in any type of weather. Since they fly above the clouds, in clear weather, only a tornado on the ground, which would prevent landing and take-off, would affect their ability to provide 24-hour operation. An extra supply of gasoline will be carried to permit a plane to land outside of the area in case ground conditions prevent safe landing. This extra gasoline capacity would also permit, under similar circumstances, that an area in which a hurricane existed could be serviced from the adjacent area. Spare fuel for approximately six hours of extra flying time beyond the eight-hour schedule is provided.

Engine failures under commercial operation have proved to be rare. The probability of engine failure of both aircraft at the same time for any of the 14 operating points is shown, based on service experience, to be once in every 82 000 years. By applying the lessons learned in the war to present-day aircraft design, it is not only possible, but practical to provide 24-hour service, under all weather conditions, by using heavier-than-air aircraft for Stratovision operation.

Costs

The cost of operating radio-equipped aircraft vs. that of operating ground stations is relatively easy to calculate. A practical example can be shown by cost comparisons in a representative area. Assume Pittsburgh to be a typical operating center, employing Stratovision broadcasting with an aircraft at 30 000 feet. Eleven 50-kw television or FM stations would be required to service the same area as could be serviced by one 1-kw transmitter in an aircraft. Because one airplane could service the same area with four television programs and five FM programs simultaneously, an equivalent coverage would require forty-four 50-kw television stations and fifty-five 50-kw FM stations! Also, approximately 33 relay stations would be required!

To make a cost comparison, it is necessary to assume that the same program, or groups of programs, would be fed into both systems. Thus the program costs would balance out. Under such circumstances, the operating cost for one aircraft is estimated to be \$200 per hour for aircraft operation and \$734 per hour for operating the transmitters and pick-up systems. This gives a total of \$934 per hour! However, the cost of providing the equivalent programs to the same area by ground coverage would be \$13 290 per hour!

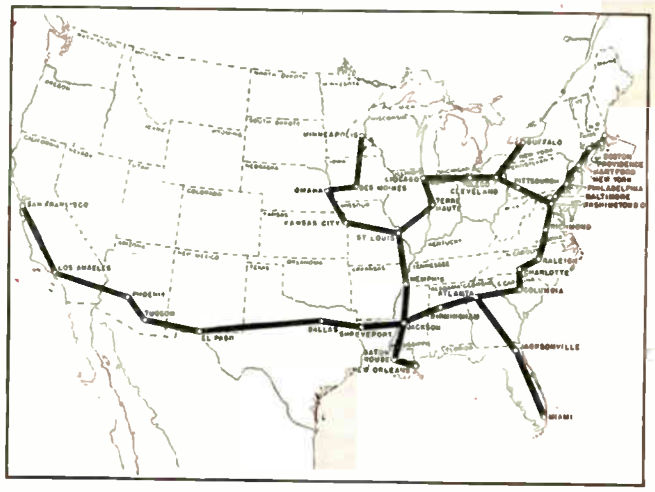


Fig. 5—Proposed coaxial television cable route.

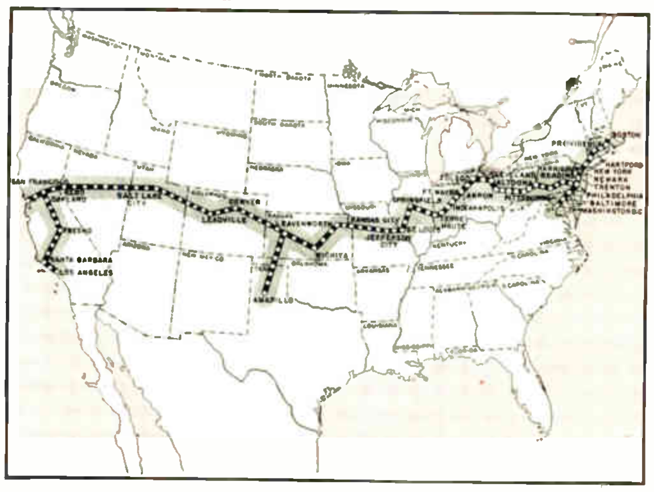


Fig. 6—Proposed coast-to-coast television-relay link, with repeater stations installed at thirty-five mile intervals.

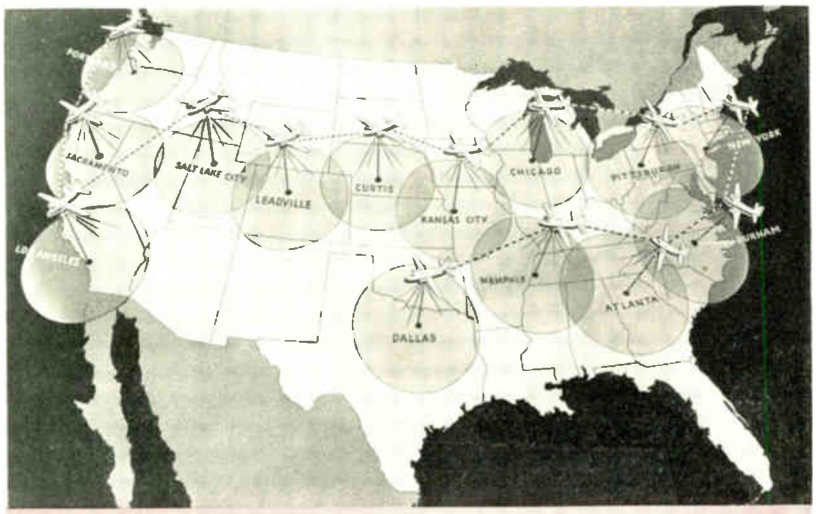


Fig. 7—Eight telecasting airplanes flying at 30 000 feet and stationed at 400-mile intervals will provide a complete coast-to-coast hookup.

Program Quality

Broadcasting downward eliminates many of the reception problems present in earlier earth-bound television and FM installations. It will, to a large extent, eliminate many of the "ghosts" that haunt the reception of programs from these stations. A ghost in television reception is a double-image caused by a signal being reflected from a hill or building and reaching the antenna a short period of time after the direct wave from the transmitter. On FM, the cause of the ghost is the same. However, it evidences itself by a change of tone in the program, destroying the high-fidelity reproduction for which FM is noted. Such a ghost exists, of course, on ordinary amplitude-modulated broadcasts and short-wave transmissions. However, in this type of service, the ghost simply causes a change in volume. Except in extreme cases this is compensated by the automatic volume control of the receiver, and the listener rarely notices it.

The Stratovision system reduces the effects of such ghosts in the region below the aircraft because its high-altitude operation enables receiver owners to point their receiving antennas directly at the circle in which the aircraft is flying—above mountains, buildings, and other sources of reflections. Directional antennas that receive signals from a narrow beam in the direction in which they are pointed and that discriminate against signals from other directions will help reduce the ghost effects, since the waves causing them reflect from the ground, buildings, hills, and other low-level points. This type of antenna is used widely in radar equipment and is now in an advanced stage of development.

In addition, the movement of the aircraft makes any small reflection that might occur of short and intermittent duration—so brief as to be undetected in many cases.

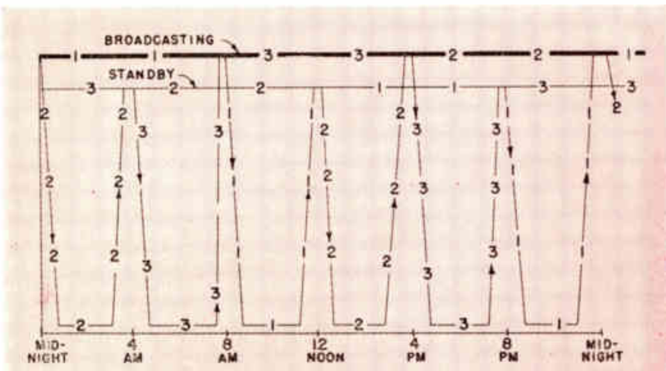


Fig. 8—Schedule by which three airplanes can provide 24-hour uninterrupted Stratovision service at each relay point.

"Spot" Television

Spot-news television programs are possible with the Stratovision system wherever they occur. Special pick-up and relaying aircraft can be provided to feed such programs into the Stratovision system from anywhere in the country. This gives Stratovision a definite advantage over any other form of television network relaying. With coaxial-cable or point-to-point radio relaying, such events can be covered only if they occur in the vicinity of the coaxial cable or near a convenient relaying point.

With the Stratovision system, however, the pick-up aircraft with portable equipment can be sent to any point in the country. By relaying through another aircraft, it could place the program right into the network, which would carry it to all points in the country. Such a service, to which the country has become accustomed in ordinary broadcasting, is thus made possible in television and FM by Stratovision.

The Future

It is anticipated that under the Stratovision system there will be two main television programs originating in Hollywood and New York City. These will be fed into the network of television broadcasting and relaying airplanes all over the country in a combination quite similar to the present broadcasting arrangement. Additional shows could be introduced into the chain at any point in the country within reach of one of the airplanes or by means of special planes dispatched to other locations. Thus, although any particular production may be more costly than present-day programs, the vast audience that can be reached reduces the cost-per-spectator to a value that is economically feasible.

The Stratovision system is about the most flexible system proposed for expanding television and FM coverage on a national scale. To extend the system, it is necessary only to station another aircraft within 400 miles of one already operating and to provide ground facilities for the aircraft and communication facilities for the operating personnel. This eliminates the expensive city-to-town-to-country expansion proposed by earlier systems. It should greatly speed up the sale of television and FM receivers, and should bring television and FM to many persons in rural and urban districts who would otherwise not receive it for many years.

Because only low-powered transmitters are required, they can be built less expensively than the high-powered ground transmitters. Consequently modern developments in television and FM in the future would mean replacing a small number of low-powered units instead of a vastly greater number of high-powered, expensive units. The use of the Stratovision aircraft as continuous weather observation stations is a possibility for the future.

Exhaustive exploratory tests of the Stratovision system are now being made. Flight tests are planned in the near future in order that the full advantages of this type of coverage may be realized as soon as possible.

Physics Gives Us—*Nuclear Engineering*

Energy from the atom! No accomplishment in all human history has such stupendous or far-reaching consequences. It affects every field of human endeavor—political, military, social, industrial, and technical. To the engineer, who until now has been only mildly interested in atomic physics, it is a new field of engineering that he must actively study if he is not to be outmoded in his profession and citizenship.

E. U. Condon
Associate Research Director, Westinghouse Electric Corporation
Vice-President, American Physical Society

To the familiar subjects of civil, mechanical, electrical, electronic, and chemical engineering, a new field has been given us by the physicists—nuclear engineering. This can be defined as the art of applying nuclear transmutations of matter to useful purposes. The subject of nuclear engineering, which has gradually been developing over the past fifteen years, is very much in everybody's mind because of its application to the making of a military weapon that ended the war eight days after it was first used.

It was considered in many official quarters that the war with Japan might have continued for another year. This might easily have meant the loss of another million American and British lives, probably the lives of even more Japanese, and a cost to us of upwards of 200 billion dollars. Instead, peace was restored at the cost of the lives of fewer Japanese and of none of the American lives that would have been lost and at a cost of only two billion dollars to ourselves. And moreover it has put us in possession of the means of assuring peace through world organization if the knowledge of the new weapon is used properly.

Before the atomic bomb, nuclear physics had provided a host of new ideas having peaceful uses—neutrons for cancer therapy, artificial radioactive materials for treatment of leukemia and of cancer, and for use in fundamental chemical studies both in biology and in chemical industry. So important had this field of work become just before the war that several large companies, among them Westinghouse, were considering the manufacture and sale of these radioactive materials. Although the war interrupted this activity and placed over all nuclear research a tight secrecy restriction, it enormously accelerated the research that ended so dramatically in three atomic bombs, one exploded experimentally and two dropped on Japan.

"... we are standing on the threshold of the era in which atomic power will be developed, surely to be the most important engineering achievement of the next generation."

With the war ended we can now devote our energies to active cultivation of the applications of nuclear engineering to peaceful purposes—to better ways of producing neutrons and high-energy electrons for therapy and of artificial radioactive materials for all kinds of uses. Moreover we are standing on the threshold of the era in which atomic power will be developed, surely to be the most important engineering achievement of the next generation.

All sorts of prognostications are being voiced about the future of atomic power. Some say it will come only in the very distant future and may not then be practical; others are rashly predicting automotive power from U^{235} in a very few years. The wide variance in predictions comes about largely, of course, from the fact that most of the prophets have little but a crystal ball to guide them.

First let us get the main points of the story in terms of answers to some questions that occur at once to every technically trained man.

What is atomic energy? All energy used industrially comes either from the work done by falling water or from the combustion of fuels—coal and petroleum products principally. In combustion of coal the atoms of carbon combine with oxygen of the air to form carbon dioxide with release of energy. The characteristic thing is that the atoms involved in the combustion process are not changed intrinsically—the carbon atom from coal is still a carbon atom in the CO_2 of the flue gas. The energy used is that made available with the formation of CO_2 molecules from C from coal and O_2 molecules from the air. This is called chemical energy.

What is being called atomic energy is the energy associated with changes in the basic chemical nature of the atoms. In a chemical reaction, atoms of the same kind are present before and after, as in the familiar combustion process

$$C + O_2 \rightarrow CO_2$$

But in nuclear reactions, atoms are made to react in such a fundamental way that the product atoms are not the same as those we start with. For example, the nuclear

$$H^1 + Li^7 \rightarrow 2He^4$$

reaction is a process that actually occurs in the laboratory, an English discovery in 1932. Hydrogen reacts with lithium to give helium! This is atomic transmutation and quite outside the scope of the classical science of chemistry.

Physicists are accustomed to expressing the energy released in terms of electron volts per atom transformed, an electron-volt being the work done on an electron when it moves through a potential drop of one volt. An electron-volt is 1.60×10^{-19} watt-second and is therefore a definite amount of energy like foot-pound in ordinary work. Chemists usually express energies of reaction in calories per gram mole of ma-

The most important source of available information on atomic power is the report on the Manhattan district project prepared at the request of Major General L. R. Groves of the United States Army by Professor H. D. Smyth of Princeton University, consultant on the project. This fascinating report is now available in book form from the Princeton University Press and is recommended reading for everyone interested in nuclear engineering. Price $2.00 cloth binding; $1.50 in paper binding. Address Princeton Press, Princeton, N. J. General Groves' office has made it clear that for security reasons all that can be said about atomic power is contained in this report. This article by Dr. Condon presents a condensed account of the atomic-bomb project as reported by Professor Smyth.

terial transformed. The heat of formation of CO_2 is about 94 000 cal per mole, that is for formation of 6.06×10^{23} molecules of carbon dioxide (for that is the number of molecules in a gram mole of any substance.) Because one calorie is 4.18 watt-seconds, it follows that the energy release in watt-seconds for forming one molecule of CO_2 is

$$\frac{94\,000\times4.18}{6.06\times10^{23}}=6.5\times10^{-19}\text{ watt-second}=4.1\text{ electron-volt}$$

On the other hand, laboratory measurements show that the energy released in the nuclear reaction by which hydrogen and lithium give helium is 17 million electron-volts per atom of lithium consumed—millions of times greater, weight for weight, than the chemical energy released in the burning of coal. The energy release in many such nuclear reactions is, generally speaking, of the order of millions of times the energy, weight for weight, released in chemical reactions.

Why is not atomic energy obtainable practically by "nuclearly burning" of hydrogen and lithium to form helium? The answer is furnished by comparison with coal. Coal (or any other chemical fuel) is valuable not only because of the energy release, but also because a self-maintaining fire can be made in which carbon and oxygen continue to burn. Of what use would coal be if a thousand dollars' worth of matches were used to burn a ton of coal? That was essentially the situation with all nuclear reactions prior to discovery of the phenomenon of uranium fission in 1939.

To make hydrogen atoms react with lithium it was necessary to ionize them and accelerate them in some kind of high-voltage apparatus. Of the many accelerated only a few struck lithium atoms in such a way as to react. The energy used to accelerate the others was wasted. The net result was that more energy is used in the experiment than that released. The overall output-input ratio was less than zero.

Hence from 1932 to 1939 we were in the position of knowing that large energy releases were possible from many different nuclear reactions—but these could be produced only in laboratory apparatus that required more energy for their operation than was liberated by the nuclear reactions.

How did uranium fission change this picture? However, as soon as the word of discovery of uranium fission reached this country from Germany in January 1939, it was at once realized by physicists that the possibility of getting atomic power in useful form was within reach. But first let us say what uranium fission is. Uranium is the heaviest atom occurring in nature. The nucleus of uranium contains 92 protons surrounded by 92 electrons. One kind of uranium nucleus, U^{235} contains, in addition to the 92 protons, 143 neutrons, giving a total weight (i.e., atomic weight) of 235. *Another and predominating kind, U^{238}, contains 146 neutrons raising the weight to 238. When a neutron strikes a uranium nucleus in the right way, the nucleus breaks up by falling apart in two approximately equal fragments with the release of about 200 million electron volts per atom split. Great as this is it is no better, weight for weight, than the reaction that forms helium from hydrogen and lithium; in fact it is only about half as good from an energy release standpoint.

Glossary of Important Terms in Nuclear Physics

Atom—Smallest unit of matter remaining unchanged in chemical reactions. All atoms are about 10^{-8} cm in diameter. They consist of a central positively charged *nucleus*, about 10^{-12} cm in diameter, surrounded by enough electrons to make the atom electrically neutral.

Neutron—A basic constituent particle of atomic nuclei having no electric charge and having a mass of about 1.67×10^{-24} gram.

Proton—A basic constituent particle of atomic nuclei having a positive charge numerically equal to that of the negatively charged electron, 1.60×10^{-19} coulomb and a mass about the same as that of the neutron. The proton itself is the nucleus of ordinary hydrogen atoms.

Electron—Smallest atomic particle. Unit of negative electricity.

Deuteron—This is the nucleus of heavy hydrogen atoms which occur in nature as about 1/5000 of ordinary hydrogen. It is the simplest composite nucleus known, consisting of a combination of one proton and one neutron.

Alpha-particle—This is the nucleus of helium atoms and is a composite nucleus of two protons and two neutrons. The name originally referred to the alpha radiation from naturally radioactive substances like uranium and radium, later recognized to be fast-moving nuclei of ordinary helium gas.

Atomic number—An integer characteristic of each chemical element which tells how many protons there are in the atomic nucleus and also how many electrons there are in the atom, outside the nucleus. Usually denoted by Z. Examples: hydrogen, $Z=1$; helium, $Z=2$; neon, $Z=10$; uranium, $Z=92$.

Isotope—A particular variety of atom or nucleus characterized by a particular atomic weight as well as a particular atomic number. Example: all uranium atoms have a charge $Z=92$, those of the light isotope have an atomic weight of about 235 while those of the heavy isotope have an atomic weight of about 238. There is also a very rare isotope having an atomic weight of 234.

Neptunium—A new chemical element not known to occur in nature having $Z=93$ and an atomic weight of 239. This is formed by radioactive decay of U^{239} which emits a β-particle (high energy electron) to become Np^{239}.

Plutonium—A new chemical element not known to occur in nature, having $Z=94$ and an atomic weight of 239, formed by radioactive emission of a β-particle from Np^{239}.

Moderator—A substance (carbon, heavy water, or beryllium) used as a means of slowing down neutrons by means of elastic impacts of the neutrons with the atoms of the moderator.

Heavy water—A kind of water whose molecules consist of the heavy hydrogen isotope, deuterium, in combination with oxygen, written D_2O instead of H_2O.

Chain reaction—Any reaction, chemical or nuclear, in which the process continues by virtue of the action of one of the products to cause the reaction to continue. Example: uranium fission is caused by a neutron and the fission process releases more neutrons which can cause more fissions.

Pile—Any arrangement involving lumps of fissionable matter, e.g., uranium, together with moderator, so arranged as to utilize the neutrons well enough to result in a chain reaction.

The essential thing about uranium fission is that the uranium atom falls apart in such a way as to produce two more or less equal fragments *—and to liberate several more free neutrons.* It is this neutron liberation that makes a self-maintaining process possible. The splitting requires a neutron to make it go—and the splitting process itself acts as a source of neutrons which can cause more uranium atoms to split. Here is the basis of a self-maintaining process, technically known as a chain reaction, such as is ordinary combustion.

Why, then, does not ordinary uranium explode or at least "burn nuclearly"? There are complications. Because several neutrons are released at every fission, a chain reaction is possible. But to make it an actuality, one of the several neutrons released must actually produce another fission to keep the process going. Otherwise the nuclear "fire" goes out.

If all the neutrons released produced more fissions the material would explode violently. But because neutrons move rather freely through matter (like x-rays) many are lost by escaping through the surface. Remedy: use a big enough lump to get a smaller surface-to-volume ratio. In other words unless the lump of fissionable material exceeds

*For convenience, the approximate weight of an element is given as a superscript to the chemical symbol. The atomic number, when given, is a subscript preceding the symbol. Thus $_{92}U^{238}$ is uranium of atomic number 92 and atomic weight 238 approximately.

a certain critical size the chain reaction cannot proceed.

Another complication is that impurities in the uranium have a powerful effect on neutron absorption. This is very difficult to remedy for appreciable losses result from the presence of only one part per million of some materials, and it is no easy matter to manufacture anything of that purity on an industrial scale.

The worst complication of all was that uranium itself absorbs neutrons in other ways than those that produce fission. This phenomenon was both a blessing and a curse to the aims of the military project. It turns out that the over-all effect of this non-fission absorption of neutrons by uranium is sufficiently great to prevent the explosion of perfectly pure uranium even in so large a lump that escape of neutrons through the surface is negligible.

Neutrons given out in the fission process are "fast," i.e., have speeds corresponding to several million electron volts of kinetic energy. Such fast neutrons colliding with uranium atoms have a rather great chance of losing energy without being caught and without producing fission.

Neutrons of intermediate speed produced this way are unable to produce fission in U^{238}. They can do so only in U^{235}, which forms only 1/140 part of natural uranium.

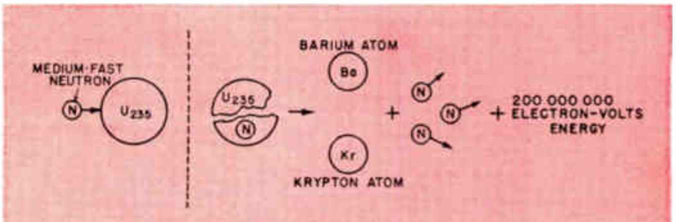
Neutrons of a particularly low energy (about ten electron volts) are very likely to be captured by U^{238} to form U^{239}. This is very important! More on this later. This happens so readily that so many neutrons are used up this way that a chain reaction cannot be maintained in ordinary uranium.

An uncaptured neutron continually loses energy by colliding with atoms as it diffuses throughout any material, until its average energy is that of the heat motion of the atoms of the material. Neutrons of certain extremely low energies are strongly captured by U^{235} to produce fission.

The clue to *possibly* making the chain reaction go with ordinary pure metallic uranium, which contains all kinds of uranium atoms but is predominantly U^{238} was to arrange the uranium in a lattice of small lumps so that many of the fast-moving neutrons would diffuse out of the uranium into some surrounding material. Here many of them would be slowed down before diffusing back into the uranium. The idea was that most neutrons would thus escape being caught by U^{238} until they had lost so much energy that capture by U^{238} was unlikely. Ultimately, though, they would return to the uranium lumps and be of sufficiently reduced speed to cause fission in U^{235}.

In the technical vocabulary of nuclear engineering this other material that keeps neutrons in custody and helps them lose energy until they are safe from capture by U^{238} is called the *moderator*. Evidently the moderator material must not absorb too many neutrons or the reaction will be stopped by this circumstance. Besides the quality of not absorbing neutrons, it is desirable to use material of low atomic weight. This is because the neutrons to be slowed collide elastically with the nuclei of the moderator material and so give up more energy at each impact if the two partners of the collision have nearly the same mass. The hydrogen content of ordinary water would be ideal from this viewpoint but absorbs too many neutrons. Heavy water is satisfactory from a neutron-absorption standpoint but previously had not been available in sufficient quantity. Metallic beryllium is a possibility but proved too expensive so that graphite was finally adopted, although not until processes were developed for manufacturing it to much higher standards of purity than is usual in ordinary industrial practice.

As this qualitative picture evolved prior to January 1942



Release of atomic energy depends on the phenomenon known as fission. A neutron moving with the right velocity strikes a uranium 235 atom (or plutonium atom), which breaks into two middle-size atoms whose total masses are very slightly less than the mass of the disintegrating atom. The difference appears as a whale of a lot of energy, according to the Einstein law of mass and energy equivalence.

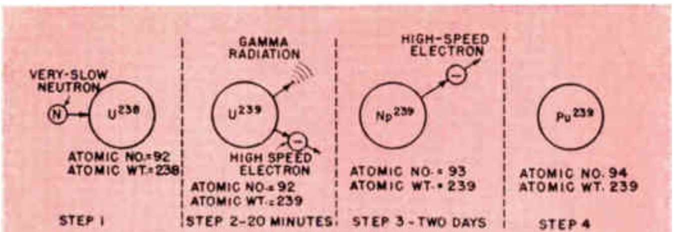
the question of whether a chain reaction would go remained unanswered because of lack of exact quantitative knowledge of the various absorptions involved. But as knowledge accumulated, it became more and more probable that such a lattice of uranium lumps and moderator—now called a pile—would go, i.e., a chain reaction continuously releasing atomic energy by fission of the U^{235} in it would be self-maintaining.

How can the pile be kept from blowing up? If a pile is so arranged that, on the average, more than one fission results from the neutrons produced by each fission, then clearly the number of neutrons present, and the amount of heat generated, increases by the compound-interest law. If a great multiplication happens rapidly—say in a small fraction of a second — then the phenomenon becomes an explosion. In short, we have an atomic bomb. Even if the reaction occurs slowly the pile would soon be destroyed by melting if the multiplication were allowed to proceed.

One way to control the pile is to provide passageways through it into which rods of material that strongly absorb neutrons can be placed. When these rods are in they absorb so many neutrons that the chain reaction is stopped. As these are slowly withdrawn a point is reached at which the reaction is just able to proceed. If pulled out farther the neutrons are able to multiply more rapidly and the pile operates at a higher power level. To stop the pile the absorbing rods are simply pushed back in farther. Cadmium and boron-containing steel are suitable materials for the control rods.

The language of the preceding paragraph implies that the time scale is slow enough for an operator to maintain control by manual operation of the rods or by use of a similar slow-acting control mechanism. That is in fact the case owing to another phenomenon in the fundamental physics of fission—delayed neutrons.

It was discovered in May, 1942, that most but *not all*



Plutonium is made by a four-step process in which a U^{238} atom absorbs a slow-moving electron. The product emits two electrons successively, resulting in a new—man-made—element of higher atomic number and mass than occurs in nature. It is plutonium, which like U^{235}, can break down.

Chronological Highlights

1905—Einstein enunciates equivalence of mass and energy.

1912—Rutherford initiates theory of nuclear atom.

1919—Rutherford discovers transmutation of nitrogen by alpha particles from radium.

1928—Quantum mechanics applied to understanding of radioactive disintegration by Gurney, Condon, and Gamow.

1932—First transformation of lithium nuclei by artifically accelerated protons by Cockcroft and Walton of England. Discovery of heavy hydrogen by Urey. Discovery of the neutron by Chadwick.

1939-40—Period of rapid development in many laboratories including discovery of artificial radioactivity by Irene Curie and F. Joliot; development of the cyclotron by E. O. Lawrence; development of electrostatic high-voltage atom smashers by van de Graaff (Massachusetts Institute of Technology), by Tuve (Carnegie Institute of Washington), by Herb (University of Wisconsin) and by the research physicists at Westinghouse. Extensive study of many nuclear reactions and parallel development of fundamental theory of nuclear structure. Much was learned about the special forces which bind together the constituent protons and neutrons in the nucleus.

1939—Discovery of uranium fission by Hahn and Strassman in Germany. First reported in this country by Niels Bohr on January 16, 1939, and immediately confirmed and further studied in many laboratories in America. Possible military applications were recognized at once by a group of physicists, among whom were E. Fermi (Columbia), E. Wigner (Princeton) and E. Teller (George Washington).

1939, March—Pegram and Fermi (Columbia) made first approach to Navy Department to advise them of possibilities in fission.

1939, July—Einstein, Wigner, and Szilard enlisted aid of Alexander Sachs of New York in getting the facts on military possibilities before President Roosevelt. Roosevelt referred matter to "Advisory Committee on Uranium" headed by L. J. Briggs, director of the National Bureau of Standards. First meeting of this committee on October 21, 1939. Voluntary secrecy policy in this field began to be set up by physicists about this time.

1940, April 28—Committee meeting to plan a larger research program. First definite reports of German activity on this subject having to do with military aims.

1940, Summer—Radiation Laboratory, University of California discovered possible use of plutonium for explosive chain reaction.

1940, Summer—Sachs active in urging more effort on this subject by contacts with President Roosevelt through his aide, General E. M. Watson. Uranium Committee under Briggs constituted as a part of the National Defense Research Committee by President Roosevelt on formation of latter body. Various small research contracts let to Columbia University, Princeton University for fundamental studies bearing on the problem.

1940-1942—Gaseous-diffusion method of separating uranium isotopes developed by a research group at Columbia University headed by Professors H. C. Urey and J. R. Dunning.

1940-1944—Investigation of thermal-diffusion method of isotope separation (on basis of research in Germany in 1938) by P. H. Abelson, first at the National Bureau of Standards and later at the Naval Research Laboratory. Pilot plant built at Philadelphia Navy Yard.

1941, Summer—Uranium Committee enlarged by addition of several new members. National Academy of Sciences Committee made an independent study of the situation. This study involved consideration of engineering problems as well as scientific problems.

1941—Development of centifuge isotope separation initiated by Professor J. W. Beams, University of Virginia. First production models made by Westinghouse, and pilot-plant test carried out successfully by Dr. E. V. Murphree, Standard Oil Development Company.

1941, Fall—Previous cooperation and exchange of data with

neutrons emitted in the fission process come out instantly. The uranium nucleus in splitting apart spills out some neutrons immediately. But the atomic fragments formed are also in a highly unstable condition and some of them throw out additional neutrons after a short time delay, amounting on the average to half a minute. It is the delayed ones that set the time scale on which the neutron multiplication in the pile builds up and set it for such a long time that slow-acting controls are easily able to regulate the activity of the pile.

The first pile was built on the University of Chicago campus during the fall of 1942. It contained 12 400 pounds of uranium, a large part of which was supplied by Westinghouse, together with a graphite moderator. It was intended to be spherical in shape but as the critical dimensions proved to be smaller than the original calculations indicated, the sphere was left incomplete, giving the actual pile the shape of a large inverted doorknob.

It was first operated on December 2, 1942, at a power level of 1/2 watt and on December 12 the power level was stepped up to 200 watts but it was not allowed to go higher because of inadequate provision for shielding personnel from dangerous radiations. Further studies on piles were made by the construction of one in Tennessee designed for 1000-kw level of operation. Later a pile using heavy water instead of graphite as moderator was built.

In summary, it should be remembered that although a pile is built with ordinary uranium, it is only the 0.7 percent of the metal that is U^{235} that is active. The U^{238} that forms most of the metal actually tends to stop the process. Only by ingenious lattice arrangement for slowing neutrons in a moderator is the pile able to operate in spite of the presence of the more prevalent U^{238}.

This means that, regarded as a fuel, only 1/140 of the total weight of uranium is being directly used; the rest is an inert material that remains largely untransformed by the pile.

How does the bomb chain reaction differ from that in the pile? The atomic bomb explodes, whereas the reaction in the pile proceeds in a slow way easily controlled by manual operation of absorbing rods. The big, fundamental distinction is that the bomb (one type) is made of essentially pure U^{235} and without the use of moderator. The chain reaction in the bomb is carried on by fast neutrons directly released by fission. As already remarked, this cannot happen with ordinary uranium because the U^{238} slows the neutrons to the point where they cannot produce fission in U^{235} and also absorbs many of them. With essentially pure U^{235} these competing absorption processes do not occur and the reaction is carried by the fast neutrons directly emitted from a U^{235} fission. These are utilized at once to produce fission in other U^{235} atoms. Here the main factors tending to stop the reaction are the loss of neutrons through the surface (which sets a minimum size to the bomb) and losses by absorption by impurities including any remaining U^{238}.

What is plutonium? This is a newly discovered chemical element not known to exist in nature but which is made from uranium by atomic transmutation. Plutonium is important because it, like U^{235}, is a material from which atomic bombs can be made.

That U^{238} can capture neutrons has already been mentioned as a phenomenon detrimental to the operation of a pile. When U^{238} captures a neutron it becomes U^{239} and emits gamma radiation as does radium. This U^{239} is not stable but emits high-speed electrons by a process of spontaneous radioactivity. The mean life of the U^{239} atoms is only about 20 minutes. By this activity they are transformed into atoms having essentially the same mass but one greater positive charge, 93, on the nucleus, and hence a new chemical element. It is called neptunium and written Np^{239}. Neptu-

of the Atomic-Bomb Project

British scientists greatly extended especially by trip of Oliphant (Birmingham) to America and of Pegram and Urey to England.

1941, Fall—Preliminary studies of atomic bomb begun by Professor G. Breit of University of Wisconsin. Work continued in summer of 1942 under Professor J. R. Oppenheimer of University of California.

1941, December 16—Top Policy Group consisting of Vice President Henry A. Wallace, Secretary of War Henry L. Stimson and Dr. V. Bush, recommended reorganization of program outside N. D. R. C. with greatly enlarged activity and Army jurisdiction. About this time the N. D. R. C. Uranium Committee became known as the O. S. R. D. S-1 Committee and was authorizing considerable expansion of the research programs at various universities.

1942, January—Major expansion of research activity authorized and started at Berkeley, Chicago, Columbia, Princeton, and several other places.

1942, April—Further cooperation with British developed during visit of F. Simon, H. Halban and W. A. Akers from England.

1942, May—Reorganization of O. S. R. D. S-1 Committee as a smaller group.

1942, June 13—Bush and Conant send to Vice President Wallace, Secretary Stimson and General George C. Marshall detailed recommendations for major expansion of the program.

1942, June 18—Colonel J. C. Marshall, Corps of Engineers directed to organize a new district to carry on the work.

1942, August 13—The "Manhattan District" was officially established for this purpose.

1942, September 17—Secretary of War placed Brigadier-General (now Major General) L. R. Groves in complete charge of all army activities on the atomic bomb which thereafter took over the previous O. S. R. D. activities.

1942—Government sponsored research at Columbia University indicated that a nuclear chain reaction was of possible accomplishment.

1942, May—Discovery by Snell, Nedzel, and Ibser of delayed-fission neutrons.

1942—Mass-spectrographic method of separating uranium isotopes developed by Radiation Laboratory, University of California.

1942, Fall—First pile built at University of Chicago (later moved to Argonne Laboratory, near Chicago) under direction of E. Fermi, W. H. Zinn, and H. L. Anderson. First operated on December 2.

1942, Fall—Construction begun at Los Alamos, New Mexico, of atomic-bomb laboratory, under direction of Oppenheimer.

1942, Fall—Design begun by Kellex Corporation of large-scale diffusion plant built at Oak Ridge by J. A. Jones Construction Company and operated by Carbide and Carbon Chemicals Corporation.

1943, Spring—One thousand-kw pile constructed at Oak Ridge, Tennessee for production of plutonium.

1943—Plant at Hanford, Washington for production of plutonium designed by E. I. duPont deNemours Company on the basis of research work at Metallurgical Laboratory, University of Chicago. Plant constructed and operated by DuPont.

1943, January—Westinghouse asked to design and build essential process equipment for large-scale mass-spectrograph separation plant at Oak Ridge designed and built by Stone and Webster. Plant operated by Tennessee Eastman Company.

1944, Summer—Large-scale, thermal-diffusion plant built at Oak Ridge, Tennessee.

1945, July 16—First experimental bomb dropped on desert near Alamogordo, New Mexico.

1945, August 6—First military atomic bomb dropped on Hiroshima, Japan.

1945, August 8—Second atomic bomb dropped on Nagasaki.

1945, August 10—Japan sues for peace.

nium 239 is also spontaneously radioactive and emits another high-speed electron becoming thereby an atom having 94 positive charges on the nucleus but still essentially of mass 239. This process is slower; the mean life of the neptunium atoms is about two days. The resulting atom of charge 94 and mass 239 is another new element that does not occur in nature. It is called plutonium and written Pu^{239}.

Actually the purpose of piles in the military project was not to get atomic power but to produce the new element *plutonium*, which provides a second bomb material. It is, in short, a competitor to U^{235}. The process by which plutonium is formed—capture of neutrons by U^{238}—has already been mentioned as one that tends to stop the chain reaction in a pile. Nevertheless the uranium lumps in the pile are exposed to a dense atmosphere of neutrons, and so the means is at hand for changing a part of the U^{238} into Pu^{239}.

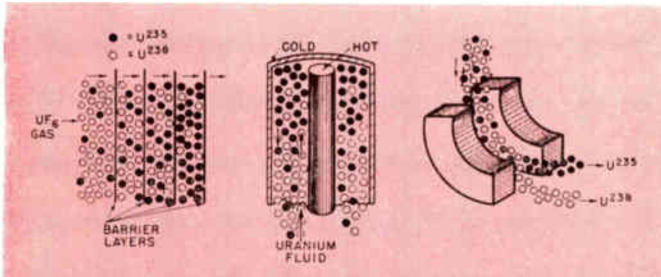
The several large piles put in operation, generated many hundreds of thousands of kilowatts as heat. This heat was, however, not utilized, as the main purpose of the operation was the production of plutonium for use in the atomic bomb. To utilize the heat would have required additional engineering to operate the pile at a high temperature and there was not time for that.

The pile when run at a high power level also generates an enormous amount of radioactive material, far more potent than all radium ever mined. This greatly complicates the problem of operation of the large piles, requiring a high standard of reliable operation that must depend entirely on remote controls.

The plutonium is formed in the blocks of uranium in the pile. These have to be removed from the pile and the plutonium extracted by fairly simple chemical methods, because plutonium and uranium, being completely different elements, are dissimilar chemically. This process, however, is greatly complicated by the intense radioactivity of the materials.

How is U^{235} separated from ordinary uranium? The makers of the atomic bomb had plutonium at their disposal. An alternative material is U^{235}. It was felt desirable, in view of all the uncertainties involved, to develop several methods and provide production facilities for extracting in almost pure form the 0.7 percent of U^{235} contained in ordinary uranium. (The third isotope of uranium, U^{234}, is present in so minute proportion as to be wholly insignificant.)

Because of the almost complete identity of all physical and chemical properties of two isotopes of the same element—in this case U^{235} and U^{238}—this is an extraordinarily difficult problem. Several methods were tried, some of which were abandoned as not operative, or as requiring too great an



The small proportion of U^{235} can be separated from the predominating U^{238} in several ways, none of them easy. Three have been used on a large scale, and a fourth (mechanical centrifuge) successfully passed pilot-plant tests. In the multistep barrier-layer method (left) the light masses pass through a little more readily than the heavy ones. In the thermal diffusion method (center) the lighter atoms tend to separate from the heavy ones under thermal action. By the mass-spectrometer method, the atoms are charged and passed through a magnetic field causing them to take separate paths.

effort, or as being too uncertain of success. These are mentioned in Smyth's report. Here we shall only deal with the three methods which were carried from the research stage into production plants. These are:

a—the mass-spectrographic method
b—the gaseous-diffusion method
c—the thermal-diffusion method.

In addition to these three methods a fourth, that of separation of gas in large high-speed centrifuges, was successfully carried to the pilot-plant stage. The centrifuges work on the same principle as the cream separator on the dairy farm, operating on the very slight difference in mass of the two uranium isotopes.

The *mass-spectrographic method* was developed by the physicists of the Radiation Laboratory at the University of California during the year 1942. By January 1943 Westinghouse was called in to design and manufacture the essential process equipment for the large production plant at Oak Ridge, Tennessee. In this method the poles of an electromagnet are enclosed in a large vacuum chamber. Uranium is introduced in the form of a volatile compound into an arc discharge which breaks the compound down and ionizes the uranium atoms.

A large potential difference between the ion source and the tank pulls these ions out through a slit in the source. Instead of moving straight across the tank, the ions are caused by the ordinary electrodynamic action of a magnetic field with a current, (the current being moving charged ions) to move in circular paths. The light ions move in a path of slightly smaller radius than the heavy ions (the ratio of the radii is as $\sqrt{238/235}$.) Therefore separate receiver boxes can be placed at the appropriate places to catch the material of each kind.

Naturally it is not as simple as this idealized description implies. The magnetic field must be exceedingly well regulated and the ripple in the high-voltage supplies must be exceedingly small; otherwise the ion beams will wander and either fail to be collected or get into the wrong receiver.

An interesting sidelight of this plant is that the many tons of conductor in the exciting coils of the electromagnets were made of silver—since the Federal Government had plenty of idle silver in its monetary reserves whereas copper was a critically short material during the war.

One of the most important features of the device is that the ion beam, in moving through the vacuum, ionizes some of the residual gas, providing free electrons that neutralize the space charge of the positive ion beam. This permits the use of beam currents; which although small, are nevertheless vastly greater than they could be if space charge were not neutralized. Without this feature the yield would be so low that this method in its present form would not be feasible.

"Power from the atom should be looked upon as another source of energy available to mankind. That it will be important is unquestioned but that it will make other energy forms obsolete is extremely unlikely."

The *gaseous-diffusion method* requires the use of the uranium in the form of a volatile compound, UF_6, the hexafluoride. When any mixed gas diffuses through a porous material, separation occurs because at a given temperature, light molecules move more rapidly than heavy molecules. However, there is only a very slight effect at a single passage through one sheet or "barrier" of the porous material. Therefore it is necessary to arrange for many successive fractionations, as in fractional distillation, at each of which only a small separating effect is obtained.

The impelling force causing the gas to flow through the barrier is of course a pressure drop that has to be made up by recompressing the gas in preparation for leakage through the next barrier. Because of the corrosive nature of the gas and of its great value after going partly through the plant, the design of these pumps presented many difficult engineering problems.

The problem of the barriers was itself of the utmost difficulty. This called for the mass production of many acres of barrier having microscopic passages of a kind that would resist corrosion and clogging up by the process gas.

The *thermal-diffusion method* is based on application of a curious and little understood physical phenomenon occurring in liquids as well as gases. In its barest essentials, thermal diffusion is this. Suppose we have either mixed gases or a mixture of two mutually soluble liquids and put them in a container that is hot in one part and cold in another—arranging matters so the material is not stirred up by convection currents. Then after a long time an equilibrium is established in which the composition of the mixture is not the same in the hot part as in the cold part. In other words a composition gradient accompanies a temperature gradient.

This, too, is a small effect and is useful only when an arrangement is made for achieving many successive fractionations so as to build up a large resultant separation. In this method the process gas or liquid is placed in a vertical tube within which is placed another tube kept hot by any means while the outer tube is kept cool. Thus a radial temperature gradient exists in the process fluid. This provides a means for a separation, which is enhanced by the countercurrent action due to convection as the hot fluid near the inner tube rises and the cold fluid near the outer tube descends.

By the spring of 1943 it was proved that this method could produce separated U^{235} with a plant whose initial cost in time and money was less than that of the other methods. The inner tubes were heated by steam and the chief drawback was the enormous consumption of steam so the thermal-diffusion plant, though relatively inexpensive to build, was rather expensive to operate.

As matters stand now separation of U^{235} from natural uranium is being done by production plants based on the three entirely different methods at the Manhattan District's reservation at Oak Ridge, Tennessee.

And now the bomb! Very little of this part of the story can be told as yet. Preliminary studies on this problem were made in 1941 and early 1942. At the end of the summer it was decided to concentrate all this work on a greatly expanded scale at a specially constructed laboratory at Los Alamos, New Mexico, about 40 miles northwest of Santa Fe. The first group of laboratory buildings, administrative buildings, homes for the personnel and barracks for the soldier guards were built during the winter of 1942–43 and the scientific staff began to arrive and start work in April 1943. What these people achieved, starting with empty buildings on a remote mesa with only an old Diesel-driven mine generator as the laboratory power supply thousands of miles from major industrial facilities and supplies, is an epic in the annals of science. The writer had the privilege of assisting with initial arrangements during the first month but was unable to stay because of other war activities at East Pittsburgh. It is to be hoped that a fuller story than is contained in the Smyth report of the achievements of this group can be given to the public before long. The story of this group, continually growing in numbers, and communicating with outside suppliers only by devious channels, because of requirements of military security, will be most fascinating when properly told.

Although discussion of the bomb's details is not permitted, these essential points can be enumerated:

a—The active material is either Pu^{239} from the piles at Hanford, Washington, or U^{235} from the three different separation plants at Oak Ridge, Tennessee.

b—A bomb less than the critical size will not explode at all so it is not possible to experiment with little ones to learn how to make a big one.

c—Before firing, the active material must be kept separated into two or more lumps each of sub-critical size. The act of firing consists of assembling these rapidly into a mass that is above critical size for that shape.

d—This has to be done with great rapidity, using a firing mechanism, which was itself a difficult problem. The need for rapidity arises from the fact that if the parts come together slowly an explosive reaction begins before the parts are completely together. This would blow them apart again and stop the fission chain reaction with only an insignificant release of the atomic energy.

e—Even with the best design possible, the stopping of the reaction due to the bomb's blowing itself apart was expected to prevent the effective conversion by fission of all the material in the bomb. Some estimates placed this conversion efficiency as low as a few percent. What was actually attained at the Alamogordo, New Mexico, tests has not been disclosed to date.

f—The fission products are extremely radioactive and if all of them were to remain in a relatively small area (say a square mile) the radiations would be too intense to permit the existence of any living matter in the region for probably several weeks after the explosion.

g—To get maximum destructive effect from the blast the bomb is fired while at a considerable height above ground, which also favors the dispersal over a wide area of the radioactive products so that the contamination of the area is not thought to be an important attribute of the weapon.

What of the future? While no reputable scientist ever makes definite promises about anything that lies in the future, still it is possible to venture an opinion that the following significant developments are highly likely to be made within the coming decade:

a—More effective ways of producing U^{235} and Pu^{239} will be developed, permitting greater production at lower cost.

b—These materials in combination with ordinary uranium will make possible power-producing piles of smaller size than those thus far developed.

c—Piles will have important peacetime uses as special-purpose energy sources, and as sources of neutrons and radioactive materials for medical and other scientific work.

d—Piles will probably not be developed into small power units for automobiles or airplanes because of their overall weight including that of the material needed to shield the passengers from the dangerous radiations.

e—Also because of shielding difficulties, piles will probably not provide the driving power for railroad locomotives. However, it is reasonable to suppose that within a decade some ships may derive their power from piles.

Besides uranium it is known also that fission may be produced in thorium, which is much more abundant in nature than uranium and therefore may be the fuel in piles of the future. Whether release of atomic energy from other materials can be achieved is a question which can be decided only by future research. At present no means of doing this is in sight—but it should be remembered that the atomic bomb would have seemed fantastic to the best nuclear physicists in 1938.

Although atomic energy may seem strange and mysterious to the engineer, it will find its application in the power field as a source of heat. The fission chain reaction makes the pile get hot. Some heat exchanger fluid must go through the pile to get out the heat. The hot fluid will then be directly used as the working fluid in a standard heat engine; e.g., a steam turbine, possibly of special design. In other words the pile is a new kind of boiler and however mysterious it may seem now, it will not require a revolution in the well-known engineering practice by which heat is converted into mechanical effort and thence into electrical power. In the meantime the most urgent problem is that of international arrangements which will assure us that atomic power will only be used for peaceful purposes.

Uranium Ores

Although uranium is contained in over one hundred minerals, only two—pitchblende and carnotite—are of great importance. It is estimated that uranium is present in the earth's crust in the proportion of about four parts per million. Early rough estimates were that the nuclear energy available in known world deposits of uranium is adequate to supply the total power needs of this country for 200 years (assuming utilization of U^{238} as well as U^{235}).

Pitchblende is found in metalliferous veins, notably Bohemia and Saxony. More recently deposits have been found in the Belgian Congo and the Great Bear Lake region of northern Canada. Most of the importations to this country during 1942 and 1943, the last years for which importation figures are available, were from Canada and the Belgian Congo.

Pitchblende of good quality contains as much as 80 percent of uranoso-uranic oxide (U_3O_8). It is a brown to black ore with pitch-like luster in the form of crystallized uraninite. Madame Curie was among the first to recognize this material as a source of radium.

Carnotite, the second main source of uranium, has been discovered in Arizona, Colorado, and Utah. It is found as a canary-yellow impregnation in sandstone. Production of this ore climbed steadily during the middle thirties from a low of 254 short tons in 1934 to a high of 6256 in 1939. The actual pounds of uranium extracted from the ore produced in 1939 were 59 269. The actual extent of deposits has not been divulged.

Until recently, the only use for uranium was as a coloring agent for ceramics and glass. It was used in amber signal lenses and in glass of special coefficient of expansion for glass-to-metal contacts in radio tubes.

" . . . . It was felt by those at Alamogordo that there was brought into being something big and something new that will prove to be immeasurably more important than the discovery of electricity or any of the other great discoveries which have so affected our existence." From the Smyth report.

What's New!

Double-Punch Insecticide

What the atom bomb did to Japanese cities the new-type insecticide bomb is doing to mosquitoes, flies, and such. From the insect point of view the earlier, pyrethrum-type bomb—of which twenty-two million were supplied to the armed forces—was bad enough. But the new one containing a quantity of the already famous DDT is even more deadly. Pyrethrum and DDT contained in the small metal can and released as a mist (aerosal) of exceeding fineness by Freon gas under pressure make a particularly potent insecticide. DDT, normally a powder, is dissolved in a hydrocarbon oil and cyclohexanone. Pyrethrum and sesame oil are also added, as before.

The entire output of the new insecticide bombs continues at the present writing to go to the armed forces.

Tomorrow's Home—a la Disney

Movies by the superb master of the color animated cartoon, Walt Disney, have been called in to help tell the story of the modern electrified home. A fifteen-minute educational sound film in technicolor, the first produced by the Disney studios for industrial peacetime purposes, has all the color, action, and imagination that characterize the series of movies beginning with "Snow White." The film is good entertainment, and at the same time, instructive.

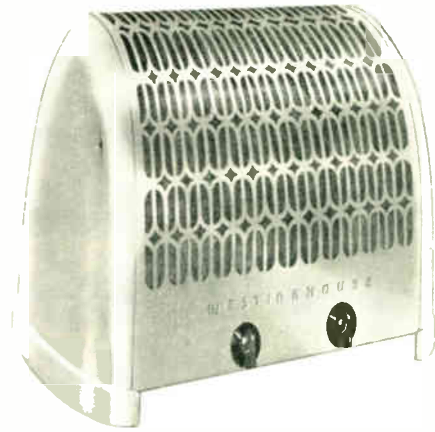
Beginning with a picturization of the development of the home from log-cabin days, it proceeds from room to room in the home, with emphasis on the kitchen-laundry, and utility room. The mechanics of living can be greatly simplified by a home designed to make maximum use of electrical aids.

Cartoons in Disney's inimitable style portray the ease and comfort that the greater use of electrical servants will bring to the average American family. It further emphasizes the importance of better wiring and points out that careful advanced planning for its installation is a must to the ultimate goal of complete electrical living.

The film will be available for both 16- and 35-mm projectors. Plans are being made for its showing after January 1, 1946, through the utilities to local clubs, engineering societies, and other group meetings. Inquiries concerning it should be addressed to Westinghouse Electric Corporation, Motion Picture and Speakers Bureau, 306 Fourth Avenue, P. O. Box 1017, Pittsburgh 30, Pennsylvania.

Electric Heating for Homes

House heating electrically has long stimulated the interest of millions of householders everywhere. It is entirely dirt-free, produces no smoke, fumes, or ashes, and is subject to simple, immediate, control. In the unit-heater form it appears to offer the maximum in flexibility both for auxiliary heating anywhere or for heating entirely by electricity where winters are mild—the west coast states for example. Heat is provided immediately by radiation and then comfortable room temperature is maintained by convection. Cold air enters at the bottom and flows upward over hollow, ceramic posts supporting nichrome heater-wires.

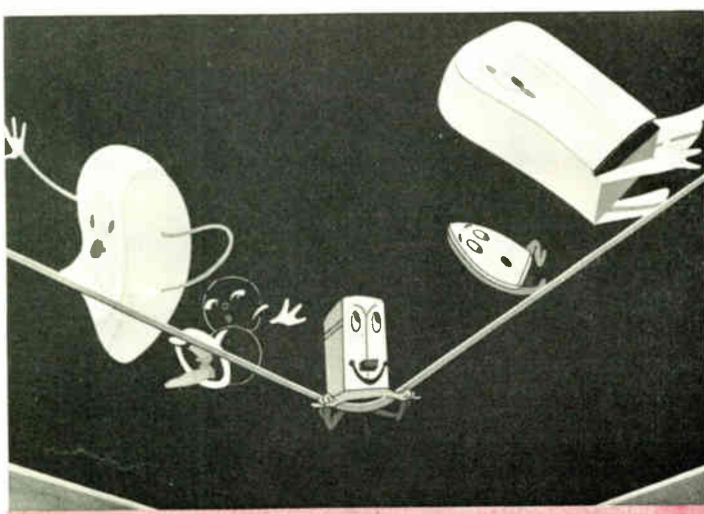


Electric unit heaters such as this provide warm, cheery heat free from dirt and smoke. They can be used anywhere for auxiliary heating or in mild climates are suitable for heating entirely by electricity

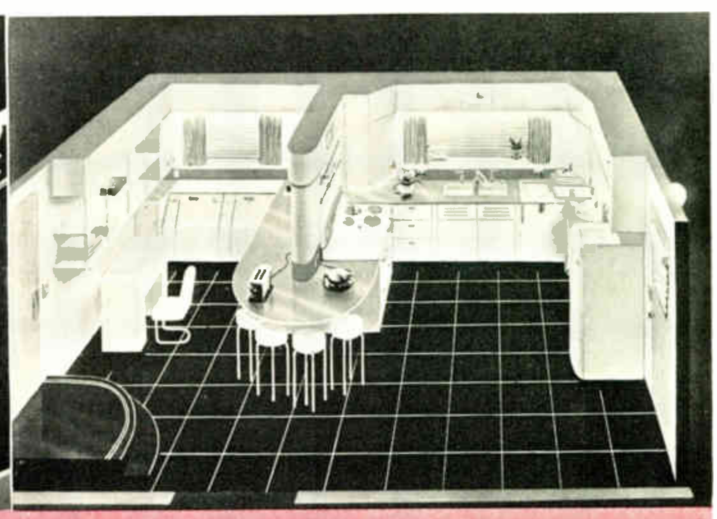
Practical Guide to Home Wiring

As with an automobile, electric house wiring grows inadequate as its owner comes to expect increased and better performance. It has been fifteen years now, what with the depression and the war, since any other than minor house repairs could be made. New, desirable electrical equipment is already promised that will seriously stress house wiring, in some cases beyond its limit. As a guide to engineers, contractors, and architects to aid in specifying adequate wiring for the present and the future, Westinghouse engineers have recently issued a booklet called *Home Wiring Handbook*.

The handbook, unlike other wiring



This fanciful cartoon, part of a fifteen-minute Disney movie, shows what happens to house circuits as more and more appliances are plugged in on the same line until it is overloaded.

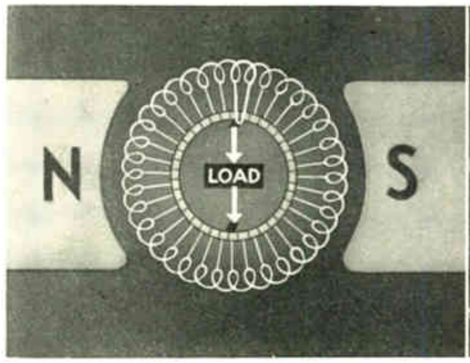


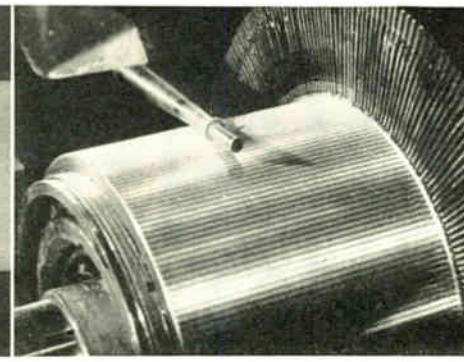
As depicted in the Disney film, the kitchen and laundry of the modern-home departments are joined with great saving of both time and steps. The electrical aids needed are emphasized.

Commutation in the Movies

A body blow to that old bugaboo—commutator maintenance—is dealt by a new movie that gives in 23 minutes the basic facts to guide operators in licking that perpetual problem. It gets down to bedrock by giving first, in animated cartoon form, the theory of commutation followed by pictures of actual maintenance operations on d-c machines, all accompanied by a running fire of instructive comment. The black-and-white film is intended for 16-mm projectors. Inquiries should be addressed to Advertising and Sales Promotion Department, Westinghouse Electric Corp., P.O. Box 868, Pittsburgh 30, Pa.

These views are taken from the movie. The first illustrates how the brush short-circuits each coil in turn as well as conducting the current into and out of the armature. The second shows how the commutator mica is undercut to prevent scoring and arcing of the brushes.





guides, not only prescribes minimum safety standards but also establishes well-engineered wiring designs. Houses are grouped into four price classes. For each group, electrical appliances now, or soon to be available, are listed in detail. The number, size, and arrangement of electrical circuits adequate to supply these and possible future loads are given for each case. Special attention is paid to insure that the proper voltage will be available at each outlet.

Simple charts are given by which the voltage drop for any wire size and load can be determined in advance. Sample problems are worked out for several examples showing the use of these charts.

Signal systems, telephones, and radio connections are difficult and expensive to install after the house is built. The handbook gives suggestions for raceways and fittings that will reduce communication wiring to a minimum and still provide great flexibility.

The protection and satisfaction of both the home owner and the contractor are assured if complete specifications are drawn up listing all electrical work to be done. The handbook concludes with a complete sample specification for a home in the popular-priced bracket that can be used as a guide for actual construction.

The book can be obtained at the nominal cost of $1.00 by addressing Industrial Relations Department, Westinghouse Electric Corporation, 306 Fourth Ave., Pittsburgh 30, Pa.

Diesel-Electric Welder

Vital repair and salvage work by the Russian Government and the U. S. Navy is now being hastened by means of a new 300-ampere, single-operator, Diesel-electric welder.

Salvage work is wherever it happens to be. Ships, tanks, and other damaged machinery cannot be moved to the orderly aisles of a factory. Repair equipment must be designed to be moved easily from job to job. Flexibility is provided by equipping the welder with four wheels, two wheels, or even with no wheels at all as the requirements demand. It can be swung aboard a ship or a plane by attaching a crane to the single lifting eye.

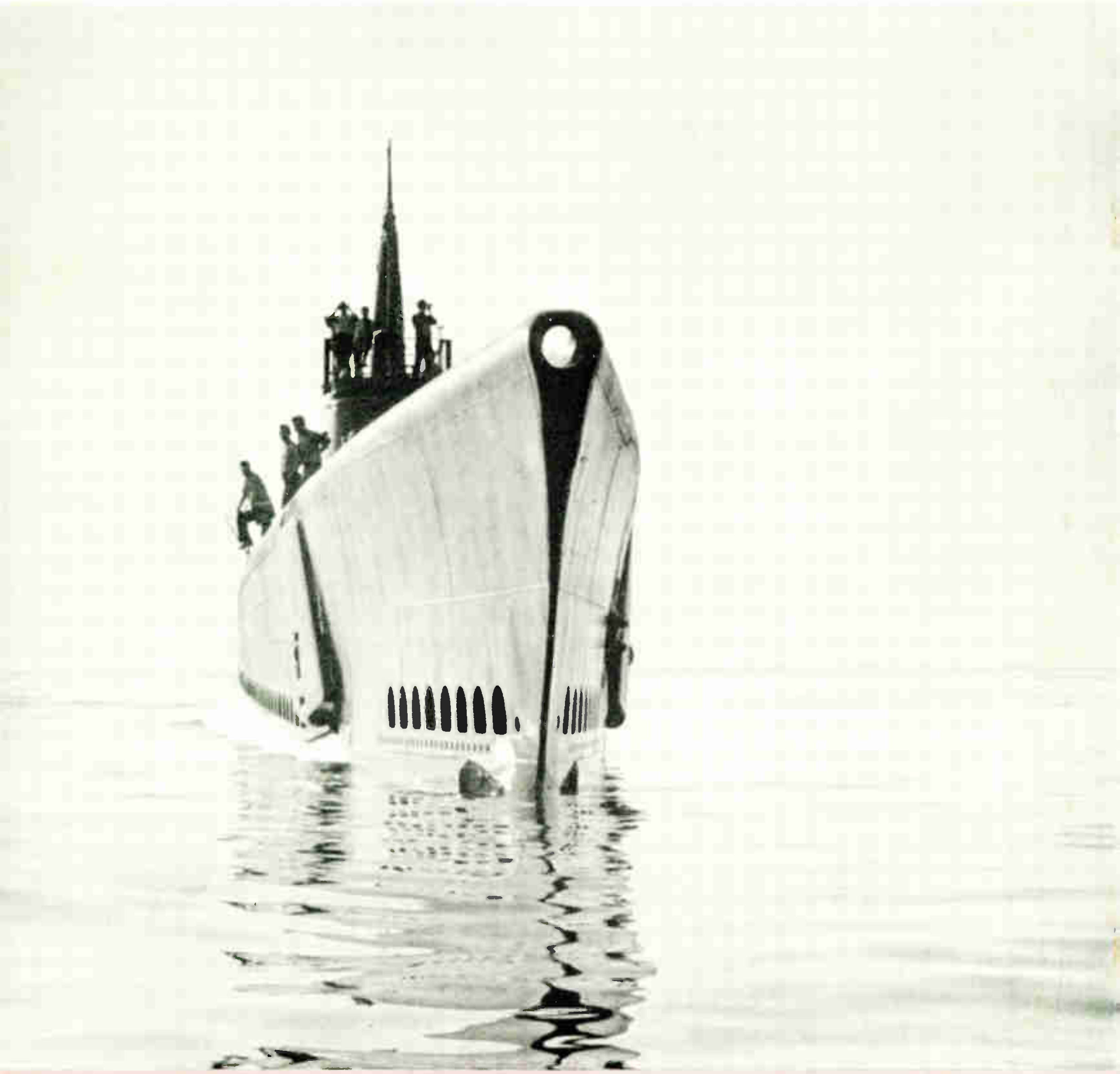
A welder must contain its own prime mover to be adapted to the on-the-spot conditions of repair work. Diesel-powered welders are higher in first cost but there are many places where no other type of prime mover can be used because of risk of fire or explosion. Diesel fuel oil is relatively inert and Diesel machines are used regularly, even in hazardous locations. Then, too, the fumes from a Diesel are less apt to contain the deadly carbon-monoxide gas and so less ventilation is required in confined quarters. Diesel engines are, as a rule, simpler, more rugged, and much less delicate to maintain—attributes that are well appreciated thousands of miles from the nearest service station or spare-parts depot.

Diesels have a low, daily operating cost, from one half to two thirds that of other types of prime movers.

The machine is equipped with a well-proven, arc-welding generator with close, preset control of the arc characteristics and current. The complete unit weighs approximately 2900 pounds. Electrical manifold heating assures easy starting.

This unit will have many uses for general welding where a simple, rugged, portable, low-operating-cost machine is required for all-weather service.

Simple, rugged, Diesel-electric welders like this can be employed in many hazardous locations such as ships where engines using other types of fuels are prohibited.



Official U. S. Navy Photograph

Secrecy and surprise, two of the most important factors in any struggle, are the all-powerful elements of naval torpedoes. Their approach must be unsuspected or the intended victim, forewarned, can elude the death-laden missiles. Torpedoes now strike their targets with even less warning than before since being equipped with electrical drive that eliminates the revealing wake of air bubbles, formerly such a dead give-away of their presence.

The Electric Torpedo—Unseen Naval Weapon

Torpedoes driven by electric motors, silent and wakeless, played a decisive role in blasting the Japanese Navy into oblivion. Leaving no tell-tale trail of bubbles behind them, they are practically undetectable.

The development of the electrically propelled torpedo was awarded to Westinghouse by the Navy in March, 1942. So important were these weapons considered that their manufacture was given a precedence rating equal to that of the Navy's top-rated rocket program.

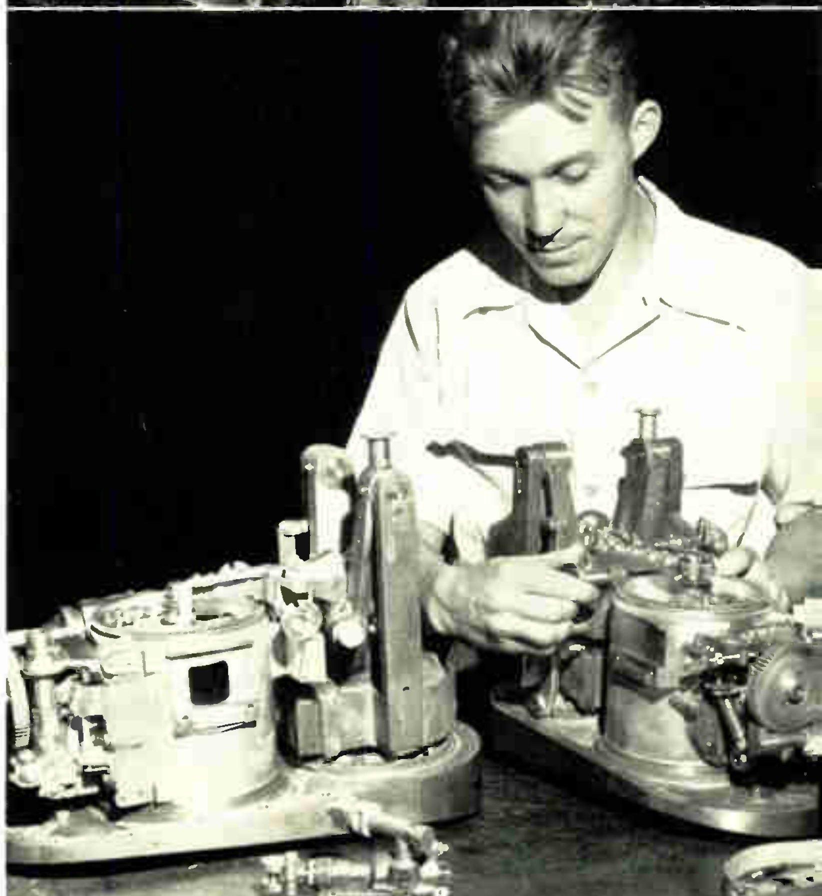
It was in 1805 that Robert Fulton first demonstrated a new method of destroying ships by exploding large charges of gunpowder against their hulls under water. Unfortunately, while the method itself was most effective, means of getting the explosive to the enemy's ships had still to be worked out. Drifting the charge on the tide was explored; a diving-boat by which the explosive could be affixed to the ship was considered.

A method successfully used in the American Civil War was to attach an outrigger torpedo to the end of a long pole projecting from the bow of the ship—to be run out when the attacker neared the enemy vessel.

Other schemes were attempted, but it remained for Whitehead with his invention of a torpedo driven by compressed-air motors operating twin-screws to make the torpedo the dreaded device that it became in the first World War. Its main disadvantage was the revealing trail of air bubbles it left behind as it ran through the water. With the advent of the electrically driven torpedo, even this warning to the intended victims was completely eliminated.

Many special design problems presented themselves in the development of the electrically powered torpedo. For example, the main propulsion motor was limited in its output by the maximum temperature that the soldered connections to the commutator bars could withstand. In initial test runs on the range, considerable trouble was experienced from solder thrown from the commutator. This difficulty was remedied by developing a special process of brazing the armature coils to the commutator segments with phos-copper that melts at a temperature of approximately 815 degrees C as compared with 200 degrees for the common types of solder.

In an electric-type torpedo compressed air is precious. The supply is extremely limited as it is used only to operate controls. Should there be even a tiny leak after the air bottle is charged, the torpedo might be entirely ineffective when shot against the



Torpedoes have only one chance to make good. The propulsion machinery, the control equipment, and the explosive must operate with perfect precision or a whole mission may be wasted. In the upper view, a worker installs coils in the special, light-weight, powerful, electric-propulsion motor. Some of the intricate direction and depth-control equipment can be seen in the middle view. Completed torpedo warheads, the pay-load for which a ship may travel thousands of miles to deliver to the enemy, are shown in the lower view lined up for inspection before being shipped.

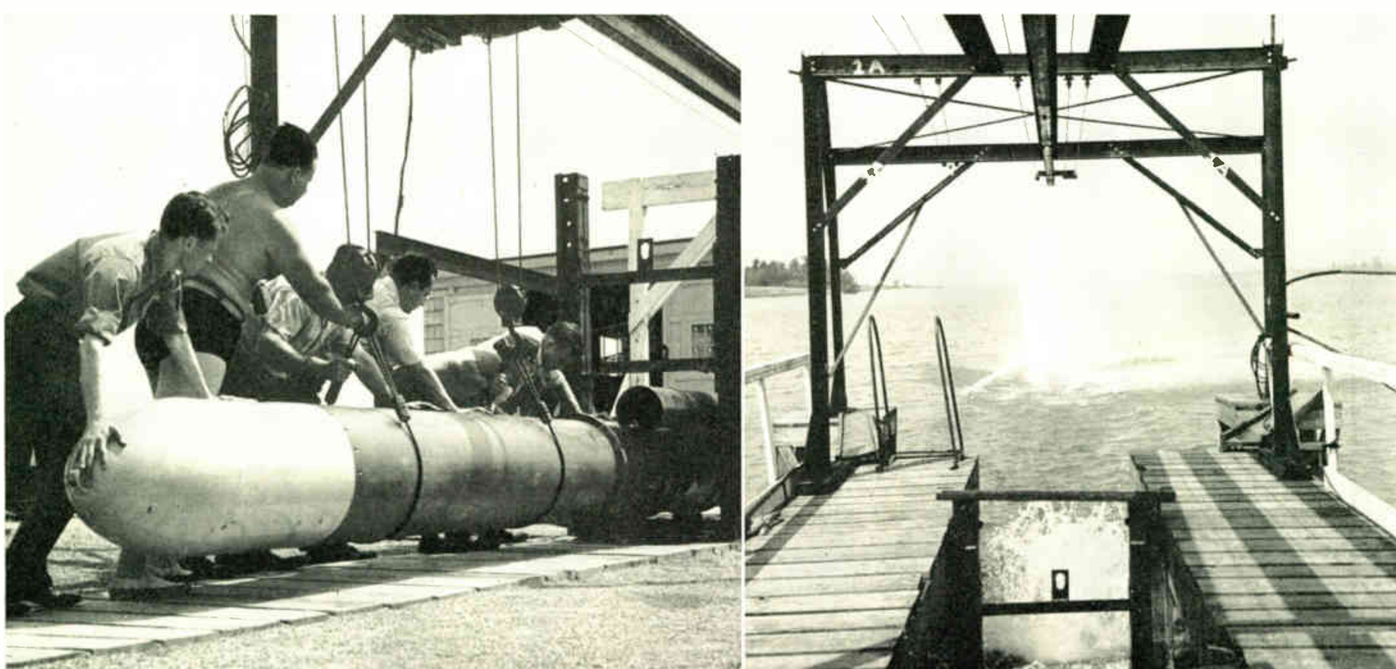
Careful checking of every step in the manufacture of naval torpedoes is a necessity. The afterbodies or propulsion ends of the deadly weapons are shown being thoroughly tested.

hull of some enemy ship. Previously, valves and valve seats in the high-pressure air system were metal-to-metal fits and had been laboriously ground and lapped. Even then difficulty was experienced with air leakage. This was overcome by the elimination of metal seats and the use instead of valve seats made of a Nylon plastic developed by Dupont Research Laboratories. Experiments showed that a small particle of metal or dust on the seat of such a valve would not interfere with its tightness in any way, and tests over periods of several weeks have been made without the loss of any air through the valve mechanism.

Another problem was that of corrosion. Torpedoes are subjected to the effects of salt water, which corrodes exposed bare steel rapidly. Heretofore the torpedoes have been coated with heavy grease to protect them from contact with salt water and a constant program of maintenance has been carried out to prevent damage. A method of Parkerizing the steel shells and assemblies was evolved. They were then coated with an acid and alkali-resistant synthetic varnish baked in an oven to form a tough, impervious film over all of the exposed steel parts. This coating is so effective that torpedoes with this protective film have been submerged for months without showing signs of corrosion.

Storage batteries tend to generate hydrogen gas. This could accumulate within the torpedo and cause a premature explosion. This danger was eliminated by inserting within the battery compartment a filament-like wire that glowed and burned off the hydrogen as it was produced before the concentration became great enough to become explosive.

Because it is necessary to test each type of torpedo made, permission was obtained from the state of Pennsylvania to set aside an area for that purpose at Lake Pymatuning, some twenty miles from the Sharon plant where they are built. There torpedoes, minus explosives in the warhead, are shot from tubes and their actions observed. Special devices for retrieving the torpedoes are installed. Ordinarily the fired torpedo floats on the surface after it is expended and is retrieved by men in a launch. On a few occasions when the torpedoes sink, a professional diver goes down to recover them for future use.



Actual water-runs are made at Lake Pymatuning, Pa., test depot. A torpedo is shown being backed into the firing tube from which it will be expelled with a blast of compressed air. The torpedo has just been fired in the picture to the right and is breaking water some fifty yards from the starting point. The torpedo firing tube is lowered into the water in the cut-away portion of the dock.

A Simple Single-Sideband Carrier System

Colored light is obtained from an incandescent lamp by filtering out all colors except the one desired. That is wasteful. With a fluorescent lamp only light of the desired color is produced. Nothing is thrown away. That is efficient. In this regard the ingenious new power-line carrier system is like the fluorescent lamp. With it only the desired single sideband is generated. The carrier frequency and the second sideband do not also have to be created and then eliminated by filtering. It makes single-sideband carrier, once ahead of its day because of its complexity, entirely practical. The system doubles the number of available channels.

R. C. Cheek
Central Station Engineer
Westinghouse Electric Corporation

Single-sideband transmission has long been known to offer many advantages in power-line carrier work.* In band width, it is the most economical system known; and with single-sideband transmission, more channels are available in a given frequency band than with any other scheme. A single-sideband communication set was once available for power-line carrier work, and it has proved itself in several difficult applications. However, this set employed the principle of generating both sidebands and using filters to eliminate one of them. A double modulation scheme was required because of the comparatively high frequencies used in power-line carrier work. As a result, the equipment was so bulky and expensive that its use was justified only for most important transmission lines.

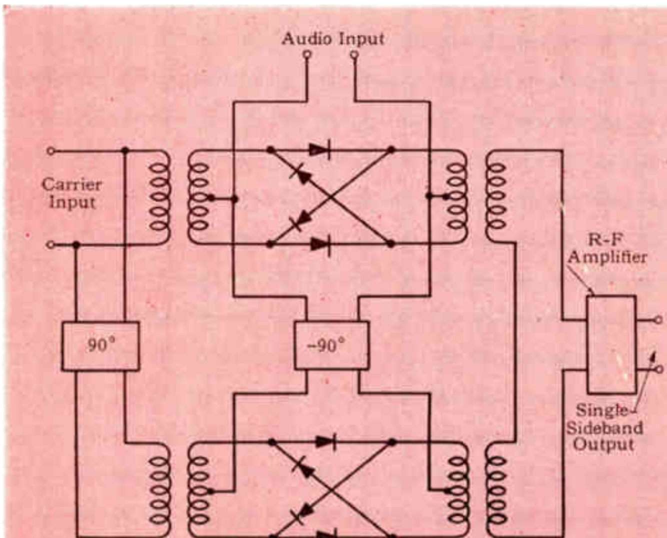
Now a simple single-sideband power-line carrier system has been developed in which only the desired sideband is produced directly. This system is designed not only for communication work but also for telemetering, load control and other power-line carrier functions, for which the advantages of single-sideband transmission have not been available previously. The absence of fixed filters makes it possible for frequencies to be changed at will, an important consideration in power-line work, where frequencies cannot always be selected before the equipment is installed. With the new system, existing amplitude-modulated equipment of proper design can be converted to single-sideband operation simply by adding single-sideband modulating and demodulating units. After conversion to single-sideband operation, the original equipment can operate through more than nine additional decibels of attenuation. Twice as many channels can be operated in a given frequency band with single-sideband equipment than with amplitude-modulated equipment.

*The principles underlying amplitude-modulated, frequency-modulated, and single-sideband power-line carrier were discussed and compared in "Power-Line Carrier Modulation System," R. C. Cheek, *Westinghouse ENGINEER*, March, 1945, p. 41.

The Single-Sideband Modulator Unit

The heart of the single-sideband system is the copper-oxide rectifier assemblies, each consisting of four rectifier discs connected in series as in Fig. 1. Each rectifier unit of Fig. 1 produces double-sideband signals, as in conventional telephone-line carrier systems. Two such modulators are used with shifts in the phase of the carrier and audio signals applied to one modulator with respect to those applied to the other.

The carrier voltage to the lower modulator of Fig. 1 is shifted forward 90 degrees with respect to that to the upper modulator, and the audio signal is shifted backward 90 degrees in phase before being applied to the lower modulator. With these phase shifts and with the connections as shown, the outputs of the individual modulators consist of identical upper and lower sideband frequencies, but the lower sideband components of one modulator are 180 degrees out of phase with those of the other. The upper sideband components, on the other hand, are in phase. The sum of the two outputs, obtained by connecting the two output terminals in series, is therefore a single sideband, the upper one, of twice the amplitude of the upper sideband generated by each modu-



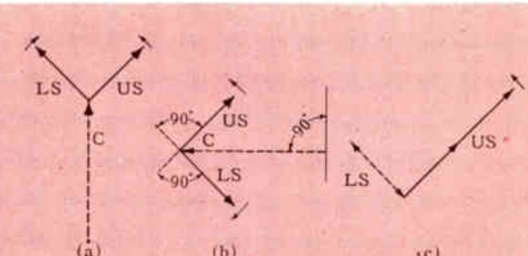


Fig. 2—These vector diagrams show how only the single sideband is generated; (a) the carrier plus the upper and lower sidebands, (b) after the audio signal is rotated backward 90 degrees and the carrier forward the same amount, (c) the final resultant with the lower sideband and the carrier waves cancelled and the upper sideband doubled in size.

Fig. 1—By rotating the carrier voltage forward 90 degrees and the audio signal vector backward the same amount, only one sideband is created by this circuit.

lator. The lower sideband components neutralize each other and do not appear in the total output.

The operation of the modulator unit is illustrated by the vector diagrams of Fig. 2. Conditions in the upper modulator are given in Fig. 2(a). Vector C is the applied carrier voltage, shown dotted because it is suppressed in the output. The upper and lower sideband voltages generated by the modulator are represented by the vectors US and LS, which revolve in opposite directions about the carrier vector at a speed depending upon the modulating frequency. The output of the modulator consists of these two voltages with phase positions as shown for a given instant. In Fig. 2(b), which shows conditions in the lower modulator at the same instant, the carrier vector is shifted forward 90 degrees. At the same time the audio frequencies applied are shifted backward 90 degrees, and the output of the lower modulator consists of the upper and lower sideband voltages US and LS with phase positions as shown. The individual sideband components combine to give a single sideband, as indicated in Fig. 2(c). The phase positions of the lower sideband outputs are such that their sum is zero at all times, while the sum of the upper sideband voltages is always twice the size of the individual upper sideband component voltages.

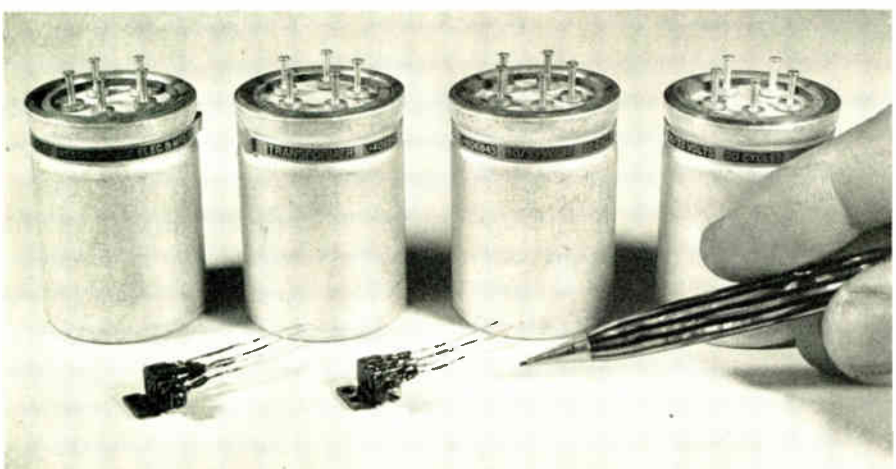


Fig. 3—These transformers and rectifier units make up the heart of the single-sideband circuit. Their simplicity and small size are of particular significance.

Reversal of any pair of connections between the two modulators, or of the output connections of either modulator, results in the production of lower sideband voltage, the upper sideband voltage being eliminated. In actual practice it makes little difference which is used, provided that all stations on a given channel use the same sideband.

The production of the single-sideband signal in this system is accomplished at a lower power level. The size of the two copper-oxide rectifier assemblies required for the modulators of Fig. 1 is indicated in Fig. 3. The complete modulator unit contains radio-frequency amplifiers, which raise the output of the device to a level sufficient to drive the converted A-M transmitter unit.

The phase of the audio frequencies applied to the lower modulator is shifted by 90 degrees, with negligible change in amplitude over the entire speech frequency band from 150 to 3000 cycles. These characteristics are required for proper neutralization of the unwanted sideband when the outputs of the two modulators are combined. The carrier-frequency phase shifter likewise produces a 90-degree phase difference between the carrier voltages supplied to the two modulators, with negligible differences in amplitude over the normal carrier range of 50 to 150 kilocycles. A change in the nominal carrier frequency of the single-sideband output of the modulator unit therefore requires a change in only the carrier frequency supplied. No adjustments are necessary in the modulator unit itself. Both phase shifters are static devices consisting of simple networks made up of resistances, inductances, and capacitances.

The Carrier-Frequency Oscillator

In any system of single-sideband transmission in which the carrier frequency is suppressed at the transmitting end, a locally generated carrier must be combined with the received single-sideband signals in the process of demodulation. A stable source of carrier-frequency voltage is required at both sending and receiving ends of the system. Naturalness of reproduction of speech signals requires that the difference between the locally generated frequency and the original carrier frequency be maintained below about 30 cycles, although usable intelligibility is obtained with differences as great as 250 cycles. In a system designed for general power-line carrier use, however, it is not satisfactory speech reproduction that fixes the frequency stability required of carrier voltage sources.

Telemetering and load-control functions are often performed by keying low-frequency audio tones, which modulate a high-frequency carrier. Selective filters are used in the tone receivers provided for the reception of these tones. The difference between transmitted and received tone frequencies must be kept within about 15 cycles for reliable operation of such tone receivers; thus frequency stability adequate for such operation over wide ranges of ambient temperature and supply-voltage variations insures naturalness of speech reproduction under all conditions.

In this single-sideband system, adequate frequency stability for all services is obtained with a newly developed oscillator circuit whose frequency is practically independent of load and supply-voltage variations. Independence from ambient temperature variations is secured by temperature-compensated frequency-determining components, mounted in a temperature-controlled box. Temperature control may not be required for some services, such as communication, especially where differences in the ambient temperatures at the sending and receiving ends are not extreme. Tuning controls are brought outside the temperature-controlled box so that the frequency of the oscillator can be quickly adjusted to any desired point in the normal power-line carrier frequency range.

A Complete Transmitting System

A complete single-sideband transmitting system consists of the basic oscillator and modulator units that have been described, plus a standard A-M transmitter unit. This standard transmitter, when used for A-M service, contains a beam-type oscillator tube in a Colpitts oscillator circuit, followed by six such tubes in a push-pull parallel untuned R-F amplifier circuit. The amplifier tubes are grid-modulated for A-M service.

When the transmitter is used for single-sideband transmission, the oscillator grid lead is removed from the plate tank circuit and is connected instead so that the tube is driven by the output of the single-sideband modulator unit. With this change and a change in the bias adjustment, the oscillator tube becomes a tuned R-F amplifier. The original R-F amplifier tubes continue to operate as amplifiers. Operating continuously at full efficiency, the transmitter produces a continuous output during full modulation equal to the output obtained only on modulation peaks in A-M service. Such operation accounts for a large part of the gain in signal-to-noise ratio obtained by conversion to single-sideband operation.

A single-sideband transmitting system such as that described is used in conjunction with one or more tone units for telemetering service, where transmission only is required and reception is not involved. For such applications the single-sideband converter consists of the basic oscillator and modulator sub-units mounted on a single panel to form one complete unit. A single-sideband telemetering assembly with two telemetering tones is shown in the block diagram of Fig. 4.

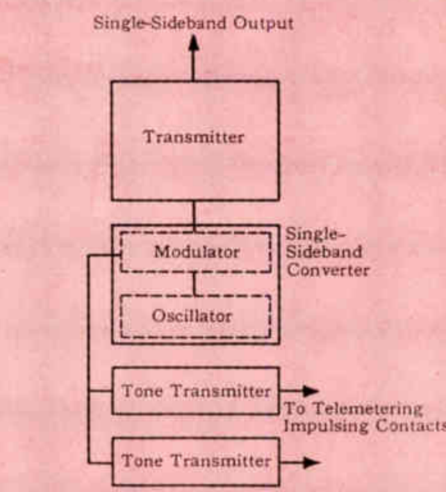


Fig. 4—A single-sideband telemetering system in which there are two tones used for transmission.

The Single-Sideband Demodulator

Reception of single-sideband signals requires that a locally generated carrier signal be added to the incoming sideband signals, either before or during the process of detection or demodulation. In the new system, the functions of mixing the local carrier and demodulating the resulting wave are accomplished simultaneously in a demodulator unit. In contrast with A-M systems, in which linear detector operation is desirable, a square-law detection characteristic is ideal for distortionless reproduction in the demodulation of single-sideband signals. Such a characteristic is obtained in the demodulator by using mixer tubes with variable-mu characteristics for the simultaneous mixing and demodulating process. The tubes used have approximately square-law characteristic curves for wide ranges of signal voltage.

The audio beat or difference frequencies between individual sideband components in single-sideband demodulators is usually minimized by using an injected carrier voltage much higher than any of the individual sideband voltages. In this way the desired difference frequencies between carrier and sideband frequencies are made much larger than any components resulting from the beating of sideband components with each other.

Suppression of these intermodulation frequencies is accomplished in a different manner in the new system. Two demodulator tubes are used in a balanced demodulator circuit with basic connections as shown in Fig. 5. The incoming sideband voltages are fed to the two signal grids in parallel, but the locally generated carrier voltage is fed to the two carrier grids 180 degrees out of phase. The demodulator plates are connected push-pull fashion to an audio output transformer. With this circuit, intermodulation frequencies produced by the beating of sideband components with each other are in phase in the two demodulator tubes, and the resulting audio-frequency currents, flowing in opposite directions in the two halves of the output transformer primary, neutralize each other. On the other hand, the desired difference frequencies between the carrier and sideband frequencies are 180 degrees out of phase as a result of the push-pull carrier input connection, and the desired audio-frequency currents are in such a direction as to augment each other in the output transformer.

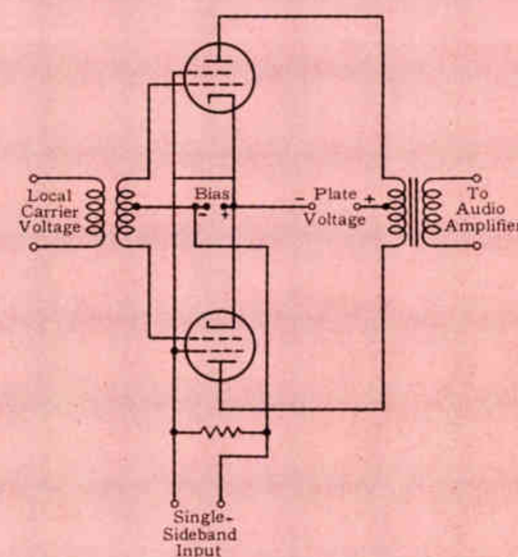


Fig. 5—The method of combining a locally generated carrier frequency with the incoming signal at the receiver is shown using a demodulator circuit.

The Complete Receiving System

In the new system, either a tuned radio frequency or a superheterodyne A-M receiver can be used for single-sideband reception. For A-M work, the tuned R-F receiver consists of a two-tube R-F amplifier, followed by a full-wave diode detector and a full-wave diode automatic-volume-control rectifier. The superheterodyne receiver consists of a converter stage, followed by two intermediate-frequency amplifiers, which feed a full-wave diode detector and a full-wave diode automatic-volume-control rectifier. Both receivers are provided with adjustable

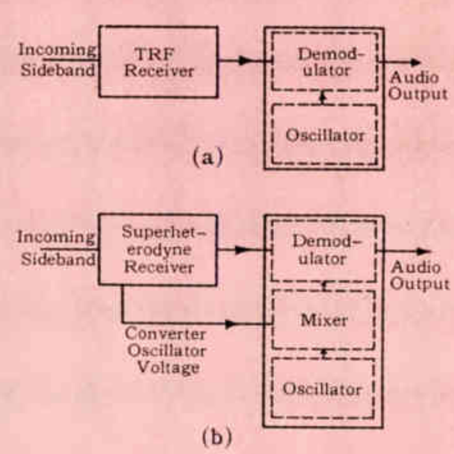


Fig. 6—Complete single-sideband receiving systems are shown in (a) using tuned radio frequency, and in (b) with a superheterodyne receiver.

selectivity. For single-sideband reception, either receiver operates in the usual manner, except that the A-M detector tube is removed and the detector stage is replaced by the single-sideband demodulator. The automatic-volume-control rectifiers continue to operate as before. This provides an automatic-volume-control system analogous to that of an audio amplifier with automatic gain control. In this case, however, the volume is controlled by the average level of the single-sideband signal before demodulation, instead of by the actual audio level of the signal after demodulation. In conjunction with the demodulator, this system provides an automatic-volume-control action that is flatter than that of the original receiver with A-M signals.

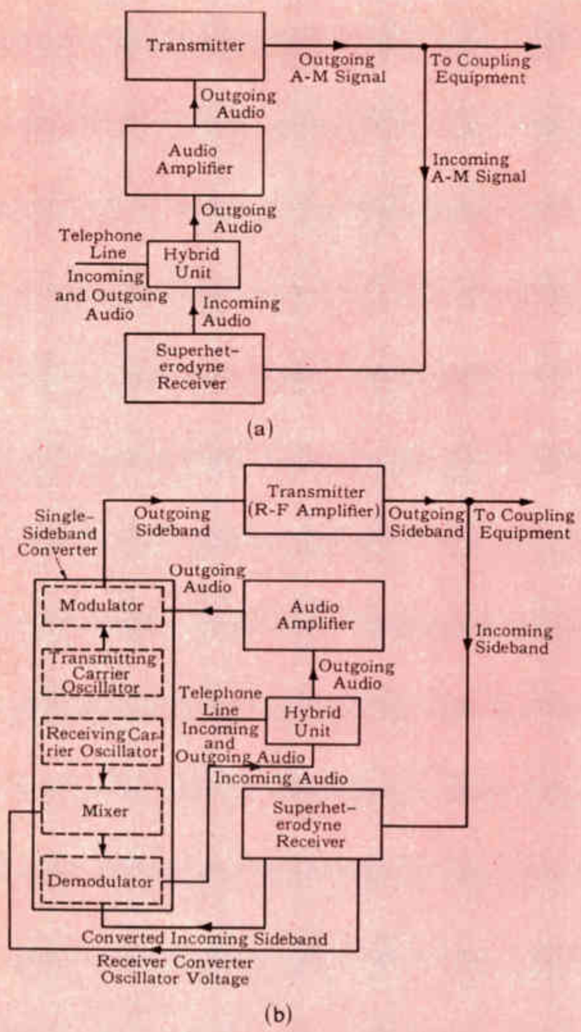


Fig. 7—Standard, two frequency, duplex unit for simultaneous two-way conversation. (a) for the usual double-sideband operation. (b) after conversion to the single-sideband system of carrier transmission and reception.

In installations where the transmitting and receiving frequencies are the same, the carrier-frequency oscillator used for transmission can also supply the local carrier voltage required for demodulation. The only additional equipment required for conversion of the tuned R-F receiver to single-sideband operation in such cases is the demodulator itself. Where the transmitting and receiving frequencies are different, however, a second oscillator is required to supply the necessary carrier frequency required for demodulation.

In the superheterodyne receiver the single-sideband signals are converted in frequency before being amplified by the intermediate-frequency stages. At first thought it appears that an oscillator of intermediate frequency is required to supply local carrier frequency to the demodulator. However, this requires an oscillator of different frequency range from those used for other purposes in the system, and it also imposes the requirement that the converter oscillator of the receiver be equal in stability to the special single-sideband oscillators. These requirements are circumvented in the new system by the use of a simple carrier converter or mixer unit.

When transmitting and receiving frequencies are the same, the oscillator supplying carrier voltage to the transmitter also supplies voltage to the mixer unit, see Fig. 6(b). Some of the receiver-oscillator output, obtained from the oscillator coil of the converter stage, is also supplied to the mixer unit. The mixer output is a local carrier signal whose frequency has been converted by the same voltage that performs the conversion of the single-sideband frequencies in the receiver. Any slight drift in the receiver-oscillator frequency results in a shift in converted single-sideband frequency, but the mixer provides a corrective shift in local carrier frequency supplied to the demodulator. Exceptional stability is therefore not required of the receiver-converter oscillator, and the same oscillator used for A-M reception is satisfactory. Where transmitting and receiving frequencies are different, separate single-sideband oscillators are required for transmission and reception, as for the tuned R-F receiver.

For single-sideband reception, the band width that the receiver must accept is only half that required for A-M reception. Upon conversion to single-sideband operation, the receiver selectivity is adjusted to approximately twice its original value, and a gain of approximately three decibels in signal-to-noise ratio is obtained as a result of the reduced amount of noise accepted by the receiver.

Single-Sideband Assemblies

The single-sideband units described are available in whatever combinations are required to convert common A-M carrier assemblies to single-sideband operation. Each combination forms a complete converter unit, in which the single-sideband units are all mounted on a single panel. A single converter unit is available for converting an A-M transmitter alone to single-sideband transmission. This is the unit shown in Fig. 4. Other converter units contain all single-sideband sub-units required to convert receivers only to single-sideband operation, as illustrated in Fig. 6. When a complete A-M assembly, including both a transmitter and a receiver, is to be converted to single-sideband operation, the single-sideband units required still constitute a single-panel converter unit.

A common type of carrier assembly is that used to perform the dual functions of relaying and emergency communication. The relaying function is normally performed by the unmodulated carrier signal, which is received on a saturated single-tube receiver. The communication function is performed by modulating the same carrier wave and receiving it on a tuned radio-frequency receiver with automatic volume control. Generally, the same carrier frequency is used at both ends of such a channel. Conversion of the emergency communication function to single-sideband operation is accomplished by adding a relatively simple single-sideband converter unit, consisting of a single carrier-frequency oscillator, a modulator, and a demodulator. The carrier wave is suppressed during operation of the communication function. When a fault

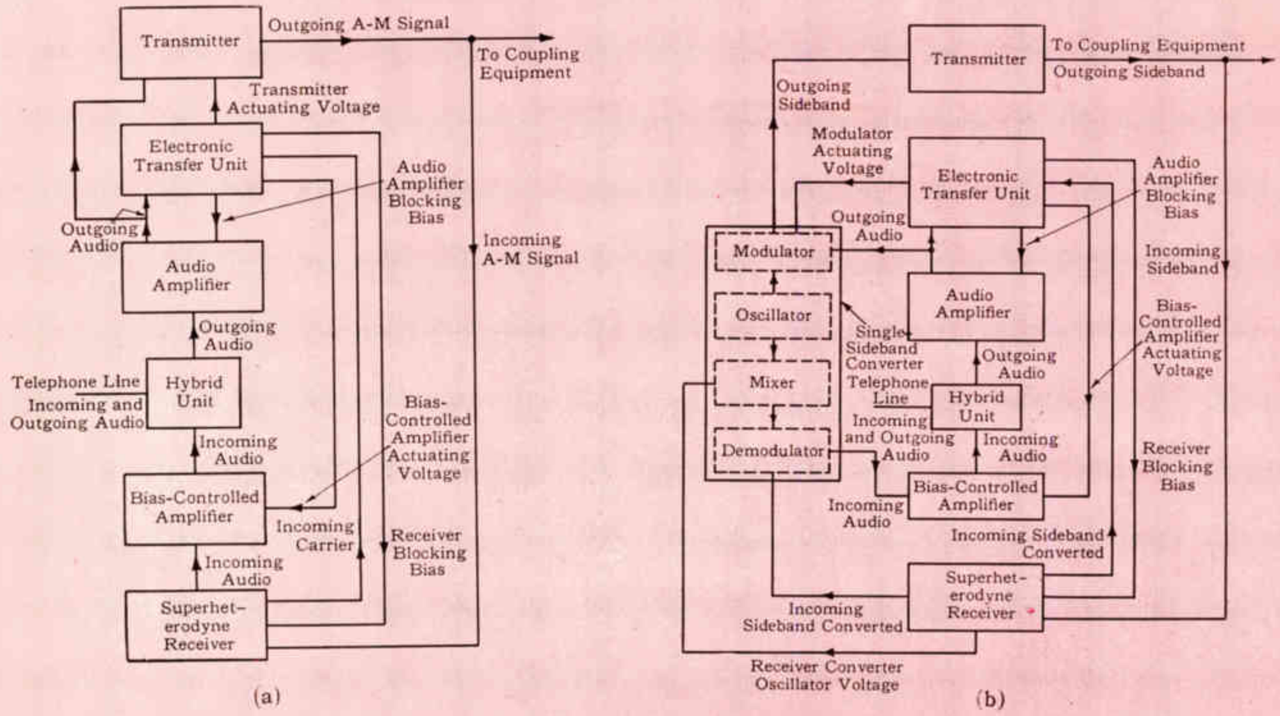


Fig. 8—In (a) is shown a single frequency, automatic, simplex transmitter and receiver for double-sideband operation, (b) indicates the units necessary to convert an amplitude-modulated power-line carrier system to single-sideband operation.

occurs and initiates operation of the relay system, however, the relays take control of the carrier equipment, and if a carrier signal is required, they insert a d-c voltage in series with the audio input terminals of one of the modulators of Fig. 1. This results in an unbalancing of the modulator and the transmission of a strong signal of carrier frequency, which is received as usual on the saturated single-tube receiver.

All the common power-line carrier communication sets available for A-M operation are also available for single-sideband operation. These include manual simplex, two-frequency duplex, and single-frequency automatic simplex assemblies. Here again the basic equipment is a standard A-M assembly, to which a single-sideband converter unit is added.

The basic units of a two-frequency duplex communication assembly for A-M operation are shown in Fig. 7(a). In this system, the transmitter at one station operates on a frequency that is received at the other station. The latter station transmits on a different frequency, which is received at the first station. The transmitter and receiver at a given station operate on different frequencies and are left on continuously during conversation. The hybrid unit contains a balanced-bridge circuit that permits the receiver output and the transmitter audio-input circuits to be combined in a two-wire line extension with minimum reaction between the circuits.

Two-frequency duplex assemblies can be converted to single-sideband operation as shown in Fig. 7. Two carrier-frequency oscillators are required in the single-sideband converter unit, because transmitting and receiving frequencies at a given station are different.

The basic units of a single-frequency automatic simplex A-M communication assembly are shown in Fig. 8(a). In this system, all transmitters and receivers on a given channel operate on the same frequency. The audio systems of all receivers are normally blocked, and all transmitters are normally de-energized. When the party at a given station speaks, the electronic transfer unit blocks the R-F amplifier portion of the receiver at that station and energizes the transmitter. At the other station the reception of the resulting carrier signal blocks the transmitter audio amplifier and energizes the receiver audio amplifier so that the signal can be received.

Conversion of the A-M assembly of Fig. 8(a) to single-sideband operation is shown in Fig. 8(b). The operation of the assembly is exactly the same except that the single-sideband modulator, instead of the transmitter, is controlled by the electronic transfer unit.

Where Should Single-Sideband Equipment Be Applied?

In the application of power-line carrier equipment, either A-M or single-sideband operation is available for any type of assembly. The question naturally arises as to what determines the choice. The most important feature of single-sideband operation—the small bandwidth it requires—makes it eminently suitable where the carrier spectrum is severely crowded. In addition to the reduced bandwidth, other features of single-sideband transmission, such as the absence of a continuous carrier signal, minimize interference.

Single-sideband operation should also be specified for channels where noise and interference are severe. The use of single-sideband equipment often makes available a channel unsatisfactory for A-M operation. This is particularly true of channels plagued with corona and resultant interference.

When the attenuation of a proposed carrier channel exceeds the rating of standard A-M assemblies, the addition of single-sideband converter units may be all that is necessary.

In some cases where A-M equipment is adequate for present needs but single-sideband operation may be required upon future expansion, A-M units should be specified mounted in cabinets with sufficient space for later installation of single-sideband converter units. Field conversion is relatively easy for such cases, requiring only a few hours' work.

Fosterite, a Moistureproof Insulation

Erstwhile practice in materials engineering was to start with a given substance and find what it was good for. This has now largely been reversed. Beginning with known requirements, a material is synthesized to suit the need—ending usually with a product of many other and unanticipated uses. Such is the family of materials known as Fosterite, achieved in the laboratory under pressure of war as a moistureproof insulation.

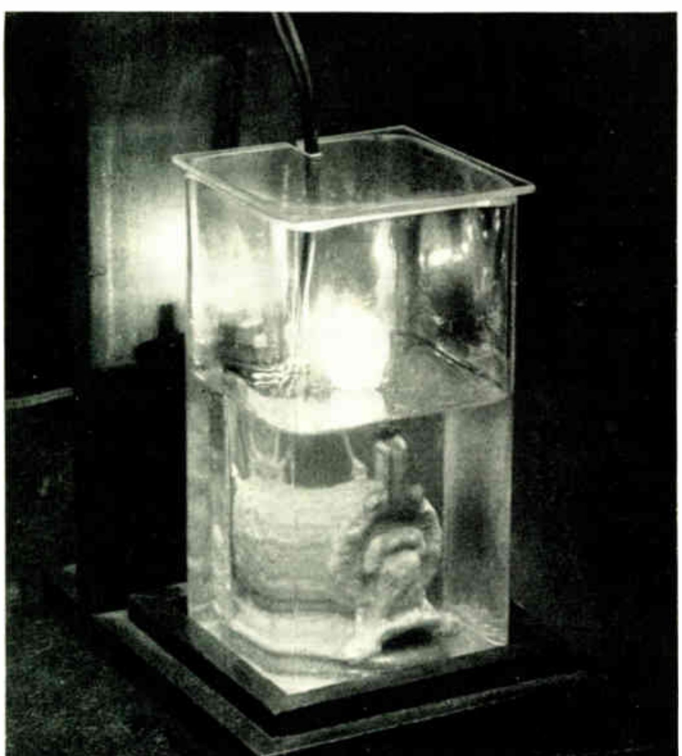
The electrical industry has long sought a moistureproofing insulation. War in the tropics, where prolonged high humidities are common, has made this desire a necessity. Aircraft operation added its special needs of low weight and heat-shock resistance as well. Airborne radio equipment in Pacific areas may undergo temperature variations of 200 degrees F in a few minutes. When a plane returns to a steaming tropical landing strip from the cold of a high altitude, the equipment quickly becomes heavily frosted and moisture soaked. The resulting high rate of failures of transformers in military communication equipment made imperative the development of some better means of sealing electrical parts against moisture.

Hermetic sealing, in cans, probably offers the ultimate in protection. However, to seal a radio transformer, for example, in a gum-filled metal case increases the weight from two to five times. Furthermore, it entails problems of seals and bushings. The cans must be filled with gum, and the high ambient temperatures may cause the cans to swell which, in turn, often develop leaks. The wide variety of cans required for the many shapes and sizes of equipment is objectionable from a production standpoint. Frequently space is not available to permit changing from an open varnish-treated apparatus to one enclosed in a sealed metal can. Improvements in moistureproofing the transformer without changing shape or size were urgently needed.

A new family of synthetic materials called Fosterite provides an excellent solution to these problems. It is a product of chemical research and takes its name from its originator, N. C. Foster. The family of Fosterites—for the material has many variants—is a plastic of the alkyd-vinyl variety. The feature of any Fosterite of great significance is that it has no solvents that are volatile under normal processing. The solvent reacts, under heat, with the resin to become a part of the final solid. Hence, since nothing is boiled off as with ordinary varnishes that contain from 40 to 60 percent volatile solvents, the finished insulation has no voids to accept moisture.

The Fosterite family of resins is readily made from relatively inexpensive and commercially available raw materials. These resins are unusual in that they are fluid at room temperature and set to a solid mass upon application of heat. The resins are thermosetting and hence do not fuse upon reheating to elevated temperatures. The liquid resins have the appearance of conventional varnishes. The family includes

This article was prepared by E. L. Schulman, Materials Engineering Department, with the assistance of N. C. Foster, Research Engineer, and F. E. Baker, Transformer Engineer. All men are members of Westinghouse.



This Fosterite-coated transformer has been under water for six months, yet it still operates and the bulb still burns.

TABLE I—POWER FACTOR AND DIELECTRIC CONSTANT OF TWO FOSTERITE IMPREGNATING RESINS

	Impregnating Resin No. 1			Impregnating Resin No. 2		
	Percent Power Factor			Percent Power Factor		
	25°C	75°C	125°C	25°C	75°C	125°C
100 cycles	0.94	2.33	0.81	0.13	0.39	0.47
1 kilocycle	0.98	2.33	2.00	0.17	0.38	1.40
10 kilocycles	1.02	2.23	3.30	0.20	0.32	2.10
100 kilocycles	1.18	2.18	4.25	0.23	0.26	1.40
500 kilocycles	1.35	2.87	3.85	0.28	0.30	1.00
1 megacycle	1.44	3.17	3.45	0.37	0.44	0.89
	Dielectric Constant			Dielectric Constant		
	25°C	75°C	125°C	25°C	75°C	125°C
100 cycles	3.40	3.65	4.12	2.92	2.96	3.21
1 kilocycle	3.35	3.53	3.99	2.92	2.95	3.16
10 kilocycles	3.26	3.44	3.85	2.91	2.94	3.08
100 kilocycles	3.20	3.31	3.73	2.90	2.93	3.00
1000 kilocycles	3.12	3.23	3.55	2.89	2.92	2.98

TABLE II—ELECTRICAL RESISTIVITY OF FOSTERITE RESINS

Encapsulating Resin No. 2			
Humidity-Percent	Temperature Degrees C	Resistivity Megohms cm.	Surface Resistivity Megohms
25	125	70×10^3	30×10^6
25	25	30×10^6	80×10^5
75	25		60×10^4
98	25		10×10^3

	Impregnating Resin No. 2	
Temperature 125°C	Resistivity 50×10^6+ megohms cm.	Surface Resistivity 24×10^6+ megohms

	Impregnating Resin No. 1	
Temperature 125°C	Resistivity 50×10^6+ megohms cm.	Surface Resistivity 24×10^6+ megohms

materials that, upon thermosetting, show a wide range of physical characteristics from soft rubbery-like materials to glass-hard resins.

The Fosterite treatment of equipment should be considered as a process and not just a material. The manner of its application is as important as the basic material itself. Equipment to be Fosterite processed must be designed to conform to certain requirements established by experience. Size must be limited if the product is to be subjected to an extreme range of temperatures.

During the processing a chemical reaction is carried out within the coil, the impregnating resin being polymerized to convert it to a solid. Care must be used to eliminate anything that would inhibit this reaction. Some gums and asphaltic materials and certain insulations will dissolve in the resin and prevent it from jelling. The only common metal that inhibits polymerization, most unfortunately, is copper. Suitable high-grade enameled wire must be used throughout.

A method was developed to fill completely the coils with Fosterite and still prevent it from running out during the polymerizing treatment. First the coil or equipment to be waterproofed is partially immersed in Fosterite that has been thickened by the addition of inert substances. This makes a heavy coating over the surface that when baked forms a liquid-tight cup, as shown on page 186. The coil is then vacuum impregnated in the required Fosterite solution and heated to polymerize the resin to a solid mass.

Characteristics of Fosterite

Fosterite resins have good electrical properties, as indicated in table I. The electrical breakdown strength is high; the material has good arc resistance. Also when arc-over does occur the arc path does not carbonize, which would result in greatly impaired electrical resistance. Some of the resins have low power factors.

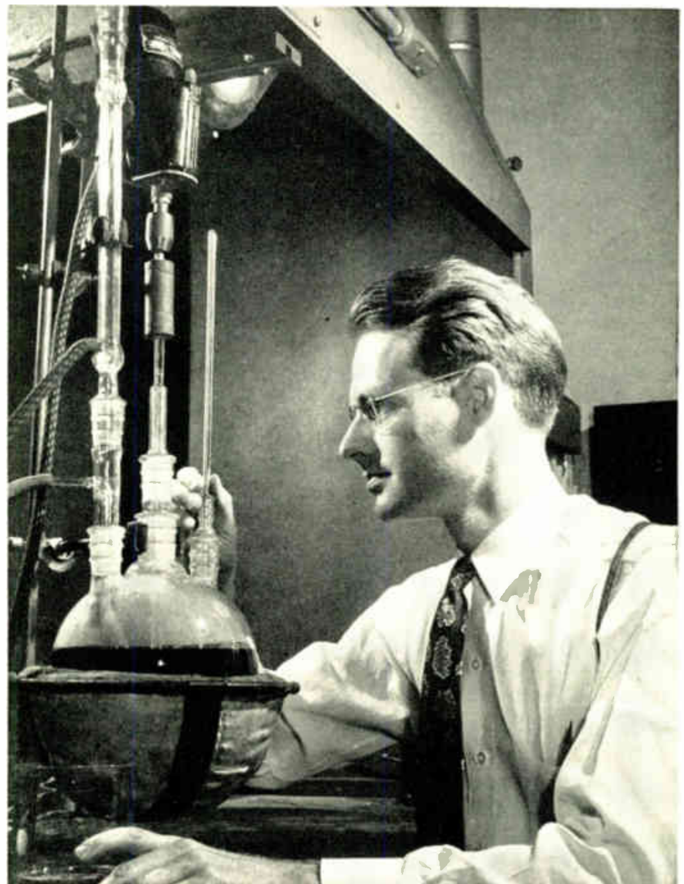
Fosterite has excellent moisture resistance, as shown in table II. In one test, a Fosterite-treated transformer is still operating after six months' immersion in water. A rectifier unit that was Fosterite-treated successfully passed a 200-hour salt-spray test, whereas varnish-treated units unless coated several times failed or corroded badly on the edges. This test indicates that Fosterite-treated equipment is particularly immune to these difficulties.

The fact that a Fosterite-treated insulation has no voids means, obviously, that air pockets are eliminated. This is of importance because the absence of air raises the corona voltage level. The rate at which heat is carried from hot spots out to the radiating surfaces is increased since there are no dead-air pockets to act as a blanket.

Many Fosterite-treated transformers are given a water-immersion test. First they are immersed in water at 65 degrees C (150 degrees F) for two hours and then in water at 25 degrees C (77 degrees F) for two hours. The subsequent insulation resistance must be greater than 2000 megohms.

As a proof of the treatment on a new design, 90 percent of all units whose maximum dimension is three inches or less must withstand full operating voltage after five cycles of heat shock from −55 to +75 degrees C, followed by 18 days at 95 percent humidity at 55 degrees C.

Equipment vacuum impregnated in Fosterite resins has a mechanically strong, solid structure. This characteristic can be accomplished because the impregnating material has low viscosity and 100-percent solids. A transformer impregnated by the Fosterite process and subsequently cut in two shows the entire structure to be solidly filled, with every wire com-



Mr. N. C. Foster, the inventor of Fosterite, is here conducting an experiment on synthetic resins in his laboratory.

These trays of transformers have been immersed in a bath of water, which is followed by an insulation-resistance test.

pletely surrounded with resin. A structure of this type has unusually good strength, an important factor in airborne equipment, which has to withstand the high mechanical forces of pull-out from a power dive.

Other Uses of Fosterite

Fosterite resins have been used in non-electrical applications where low viscosity and 100-percent solid content are particularly desirable. Occasionally, water-cooled bearing castings, or die-cast metal pressure cases are porous. Attempts to plug the pores with conventional varnishes fail, because varnishes thinned sufficiently to penetrate into the pores have such low solid content that, on evaporation of their solvents, they do not block the voids. Fosterite resins with viscosities as low as water have been successfully used for saving porous castings that otherwise would have to be scrapped.

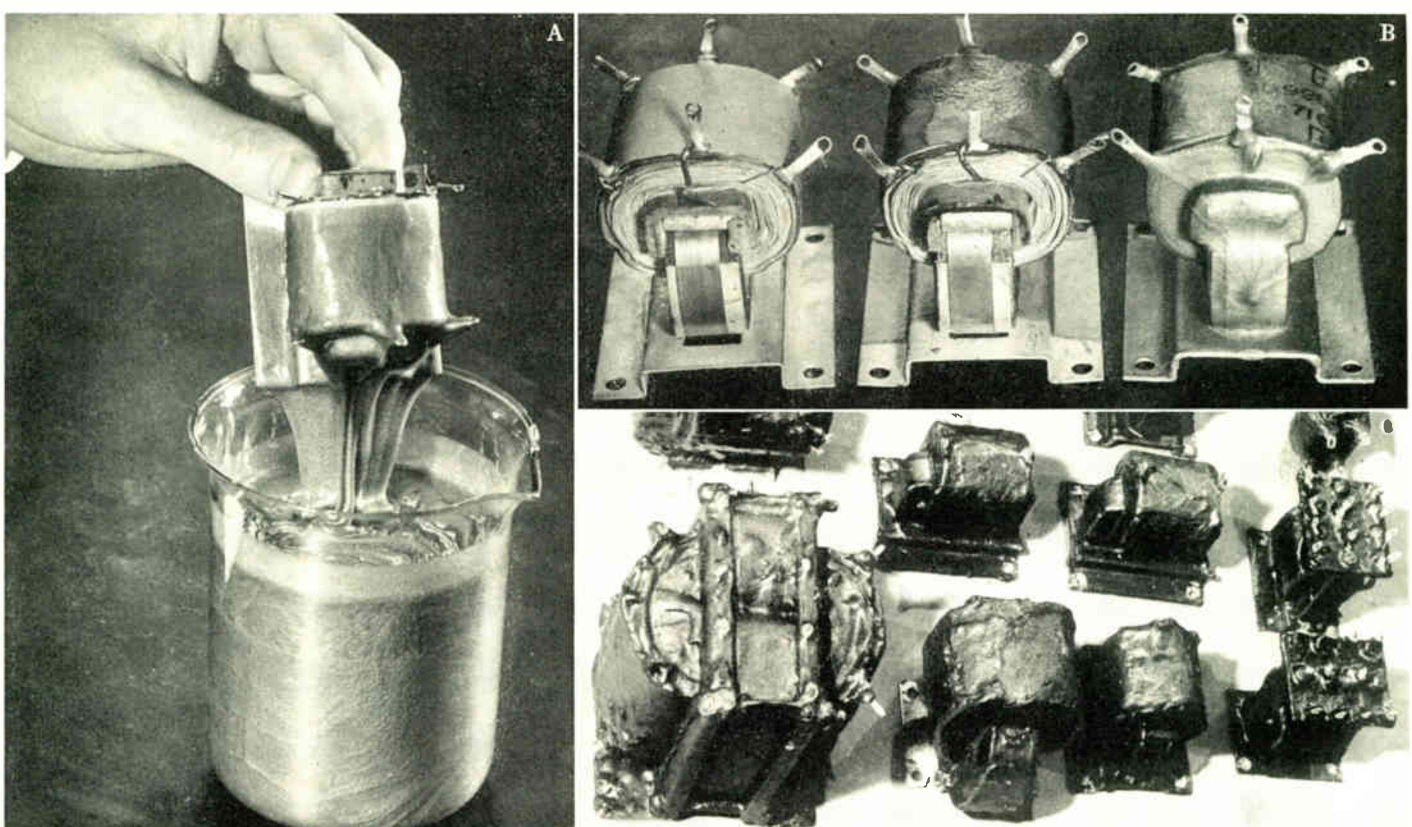
Some of the Fosterite materials are excellent laminating resins. Their low viscosities allow the resins to impregnate the laminating media instead of merely coating it. Complete impregnation has been proved to impart considerably better electrical characteristics to laminations than the surface-coating process. For some applications, Fosterite-treated cloths can be laminated at pressures less than 100 pounds per square inch. Standard Micarta products require 500 to 1000 pounds-per-square-inch pressure to laminate the fabric plies adequately.

Asbestos paper, impregnated with Fosterite resin and then laminated at 1000 pounds-per-square-inch pressure, produces an excellent electrical insulating material. The arc resistance of this laminate is about as high as shellac-bonded mica or a value of 190 seconds (ASTM) Also the material does not carbonize under electrical flashover, i.e., it does not track. In comparison to these values, phenolic-bonded laminates have only a 5-20-second arc resistance, and they track very readily. The dielectric strength of an asbestos-paper Fosterite laminate is 400 to 500 volts per mil (short-time test) or about 50 percent of shellac-bonded mica.

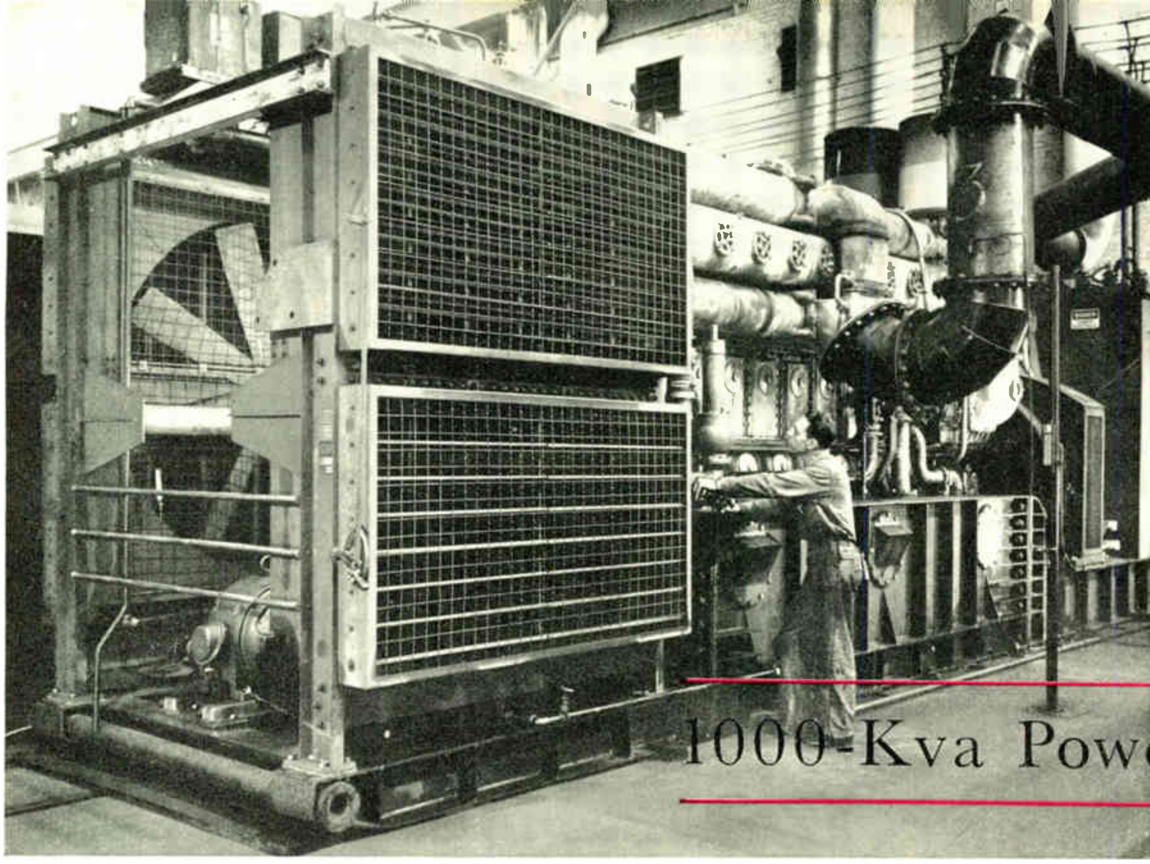
A promising application for asbestos-paper Fosterite laminates is in the bar insulation of commutators. Motors and generators with this material in the commutator have been in service for more than two years with excellent results. Coil-support channels, commutator flash rings, and many other shapes are now in production. The insulation is class B and can be operated continuously at 115 to 125 degrees C.

Fosterite resins are so versatile in their scope that the applications for them are innumerable. It has been pigmented and used as a casting resin, as an adhesive for core bonding, as a mica bond, as a potting compound and for many other applications. As more time is spent on the investigation of this family of resins, it is certain that many more important uses for it will be developed.

Note: *At present, except in a number of military applications, the Fosterite process is being limited to apparatus of Westinghouse manufacture. Because the process is so different from the usual varnishing practice, special training of manufacturing organizations is required.*



The proper application of Fosterite is as much a part of the process as the resin itself. Difficulties resulting from the water-thin impregnant draining away during the heat treatment are overcome as shown above. In (A), the equipment, in this case a radio transformer, is dipped part way into a viscous Fosterite solution to form a cup. After this is baked, the cup is filled with the regular solution and the apparatus is heat treated again. In (B) the three stages in the impregnation of a transformer are shown. The first is of the transformer before treating, the second shows the equipment with the Fosterite cup in place, while the last is of the transformer ready to be installed. A collection of completely moistureproofed radio transformers is shown in picture (C).



The power sled is divided into three parts with the cooling fans and radiators in front, the Diesel engine in the middle and generator with its controls and relays in the rear.

1000-Kva Power Sleds

War-stricken villages are in no condition to pull their own weight unless their living conditions and safety from disease and want are restored as promptly as possible. Quickly available, large portable power plants in many cases can assist mightily in the task of returning ravished communities to productivity and normal living.

RECONSTRUCTION of war-ravaged areas requires larger blocks of electrical power than can be provided by portable equipment of sizes heretofore available. Designed to meet this need are power plants on skids that can develop 1000 kva. The power sleds are sufficiently large for most applications, yet they are easily portable to the scene of need. They can be assembled readily at the site of operations within two days if sufficient manpower is available.

These Diesel-electric plants accomplish the seemingly incompatible requirements by being constructed in three separate parts, each part being mounted on its own individual skid. Each of these parts is small enough to be carried on a large highway truck or a flatcar. The power plant is complete in itself; it includes its own cooling system, Diesel engine, and control equipment for both the engine and the generator.

The Diesel Engine. The Diesel engine is located on the middle skid of the group of three. These engines were originally built for the United States Navy to be used as marine propulsion units. The engines are of the two-cycle double-acting type and are equipped with nine cylinders each. They can be set to operate at either 600 rpm for 60-cycle operation or at 500 rpm for 50 cycles. A solid-fuel injection system is employed with an individual pump for each end of each cylinder. Spring-loaded, differential-area needle valves are used and are located in the cylinder head. The governors are designed so that they will hold the speed within plus or minus one and one half percent of the desired operating rate.

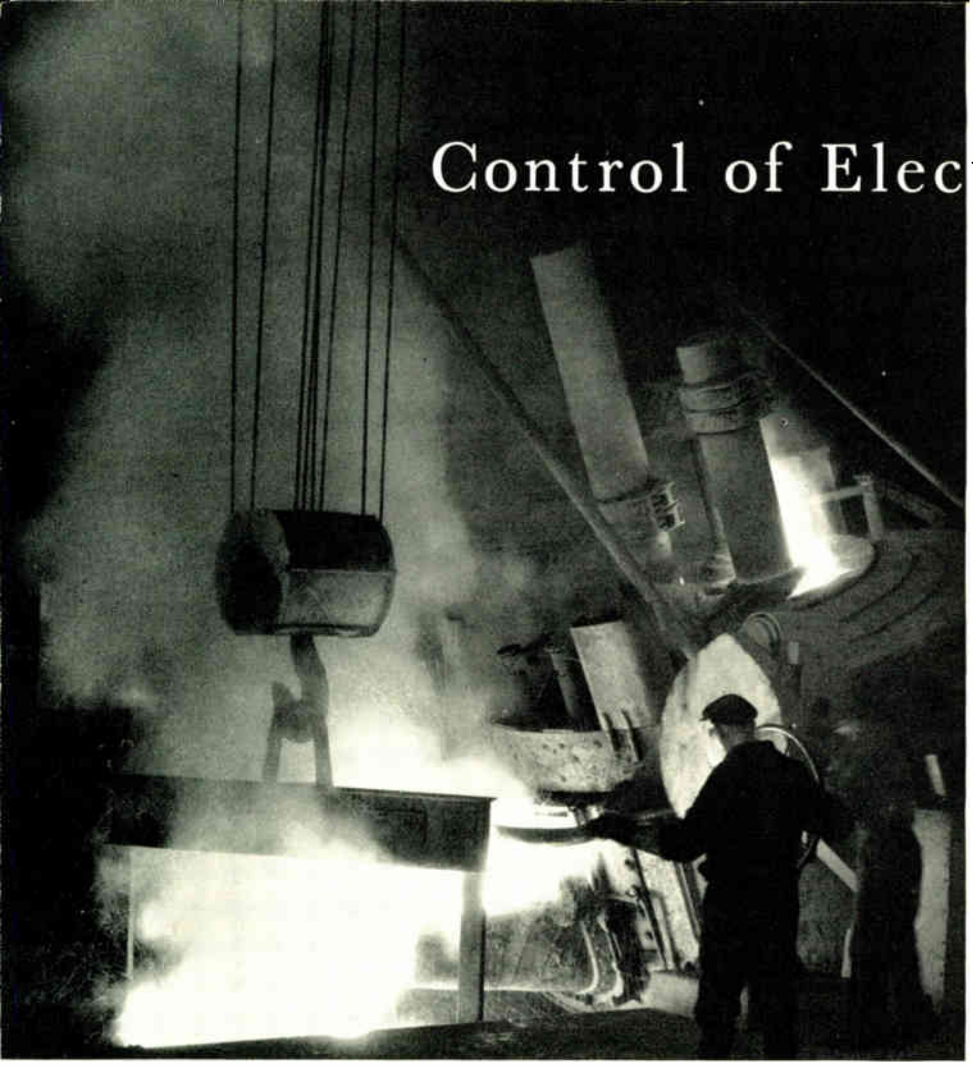
Cooling System. Two radiators, one for a fresh-water circulating system rated at 350 gallons per minute, and the other for lubricating-oil cooling are both mounted on the forward sled. Each radiator has its own 70-inch fan driven by an individual 20-hp motor. The motors are energized through breakers from the station-supply transformers. In an emergency, when the breakers would normally trip, they can be held in by a switch so that the cooling system can be kept in operation until repairs can be made.

Electrical System. The generators are of the revolving field, two-bearing, pedestal type and are direct connected to the engine. They are built so that they can revolve in either direction as dictated by the engine. Their rating varies with the speed and is stated as 1000 kva at 60 cycles or 833 kva at 50 cycles. Special endbells with screened covers are used to protect the windings from water, rodents, or insects that might be encountered during field use. Space is saved by mounting the exciter directly upon the generator frame. Special insulation is used throughout to insure the greatest reliability under widely ranging ambient temperatures and loads. The generators are equipped with damper windings to permit parallel operation if necessary.

The electrical controls are mounted in a steel, weatherproof cubicle on the rear of the generator sled. The three-phase circuit breaker is rated at 7500 volts, 600 amperes, and has an interrupting capacity of 50 000 kva. It is electrically operated and has a manual closing device and automatic time-delay trip to take care of overloads or short circuits. The output voltage of the generator is maintained within plus or minus one percent at all loads up to full load by a direct-acting Silverstat regulator.

Synchronizing can be done automatically. Manual equipment is provided for control of frequency and amount of load to be carried. The control board also carries the necessary ammeters, voltmeters, wattmeter, power-factor meter, frequency meter, elapsed-time meter, governor-motor control switch, and the controls for the two cooling fan motors. All instruments and meters are designed for high impact resistance to withstand the shocks of moving and vibration.

The power sleds are being built by the General Machinery Corporation, at Hamilton, Ohio. Electrical equipment such as generators, circuit breakers, and control panels containing instruments and relays are supplied by Westinghouse.



Control of Electric-Arc Furnaces

H. G. Frostick
Steel Mill Engineering
Westinghouse Electric Corporation

The electric arc is a fearful and fascinating phenomenon. It has a difficult disposition. It has destructive effects that harass the transmission of electric energy. Yet when created in the electric furnace and harnessed by suitable control, the electric arc is a stable, if not docile, medium for heating.

Recent years have seen the addition of two new mechanisms for regulating carbon-arc furnaces. The traditional method, called the balanced-beam system, had been developed early in the history of arc furnaces. The rotating-type regulator, developed within about the past ten years, was also found useful as a furnace regulator and has become competitive to the balance-beam regulator. More recently, electronics, seemingly capable of anything, has become the basis of an arc-furnace control system. Each device has its individual merits; no one of them has any advantage so sweeping as to displace the other two. All three systems are based upon the same fundamental scheme of measuring arc voltage and current, a method that has proved itself throughout the years.

Arc Furnaces and the Problem of Their Control

The steel-melting furnace is a fabricated steel shell mounted on a tilting mechanism. It is lined with a refractory in which a tap hole and a pouring spout are placed. Steel furnaces are built to hold up to 100 tons of charge. Steel scrap forms the bulk of the furnace charge.

Projecting into the furnace through the roof are the carbon electrodes. Power is usually supplied to these through a circuit breaker from a specially built furnace transformer connected to incoming lines whose voltage generally lies between 2200 and 33 000 volts. The electrodes, gripped in holders, are movable both to accommodate wear of the carbons by the arc and to meet different and changing depths of charge. Control of furnace operation is by regulation of electrode position. This is the function of the regulator.

The type of furnace in which the arc is placed determines to a great extent the amount of electrode movement required to compensate for electrode vaporization or melting. Two types of arc are used, the open arc and the submerged arc. The open arc is established in air in either a direct arc furnace or an indirect arc furnace. The direct open-arc furnace uses the material to be heated as one electrode and a carbon or graphite rod per phase as the other. Practically all steel melting and refining furnaces are of this type. Since one electrode is the furnace charge and the arc is changing the charge from the solid to the fluid state, considerable movement is required of the carbon or graphite electrodes to maintain the arc across the gap terminating on the melting material.

The indirect open-arc furnace is generally operated single phase and uses two carbon or graphite electrodes. These are arranged so that the arc is established in air between the electrodes. The energy of the arc is radiated to the furnace charge. This type of furnace is used largely in the melting of non-ferrous materials and the electrode movement required is largely to correct for electrode erosion caused by vaporization.

In the submerged-arc furnace the ends of the carbon electrodes are placed into the material to be heated. Usually used in ferro-alloy furnaces, the furnace charge is finely and more or less uniformly divided. The electrical conductivity of the charge is regulated by its coke and carbon content. The furnace shell or a second carbon rod may be used as a second electrode. Heating is achieved by conduction between the electrodes, as well as by the arc from the electrodes to the charge and between the divided particles of the charge.

The refining phase of the furnace operation is comparatively easy on the arc regulator. The furnace charge is fluid and all that is required of the arc is sufficient heat to maintain furnace temperature. The molten bath is relatively quiet, and the power input to the furnace comparatively light.

It is during the melt-down phase of furnace operation that the regulator performance is taxed. The furnace charge composed of various shapes of scrap must be melted, and melted as fast as the heat receptivity of the charge will permit. The electrodes in doing this tend to bore through the charge, melting the material immediately beneath the arc. Occasional cave-ins, scrap falling against the electrodes, cause heavy upsurges in current. It is against the disruptive effects of the melting charge, the tumbling scrap and the vaporizing carbon electrodes that the regulator must maintain a constant power level.

The submerged-arc furnaces are somewhat easier regulating problems. This furnace is usually stationary with an open top into which the furnace charge is hand shoveled. The charge is regulated as to particle size and electrical conductivity. The charging process is practically continuous and the tapping a matter of timing. The electrode activity is largely the following of the level of the molten bath during the tap operation, the correction of change in charge level during feeding and stoking, and compensation for consumption of the carbon electrodes.

The Arc and How It Is Controlled

An enormous electric stress is required to break down air at atmospheric pressure, but once the air is disrupted and a spark is passed a fairly small voltage can maintain a current across the gap. The sudden explosive flow of current when air is broken down by high electric stress is the spark. The current that follows at a low voltage is the arc. Usually where the arc is used as a heat medium, it is started not by a high electric stress but rather by bringing the electrodes together mechanically to cause the spark, then drawing the electrodes apart to establish the arc.

The arc has distinctive features which enable it to maintain itself at comparatively low voltages. First, the arc confines itself to a relatively narrow path between electrodes. It therefore produces an intense heat at a small point on the electrode. If the arc is long continued, this small hot point formed on the electrode is brought to incandescence, melted, and even vaporized. When this occurs, the molecules of vapor are charged as they leave the electrode and assist in carrying the cur-

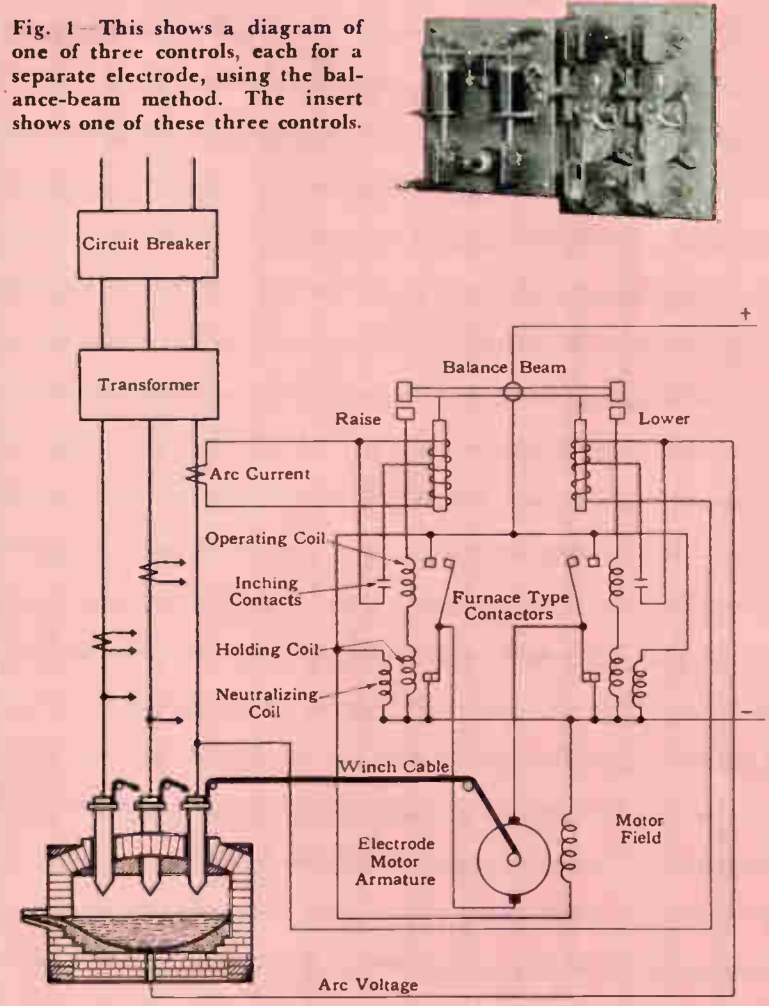


Fig. 1—This shows a diagram of one of three controls, each for a separate electrode, using the balance-beam method. The insert shows one of these three controls.

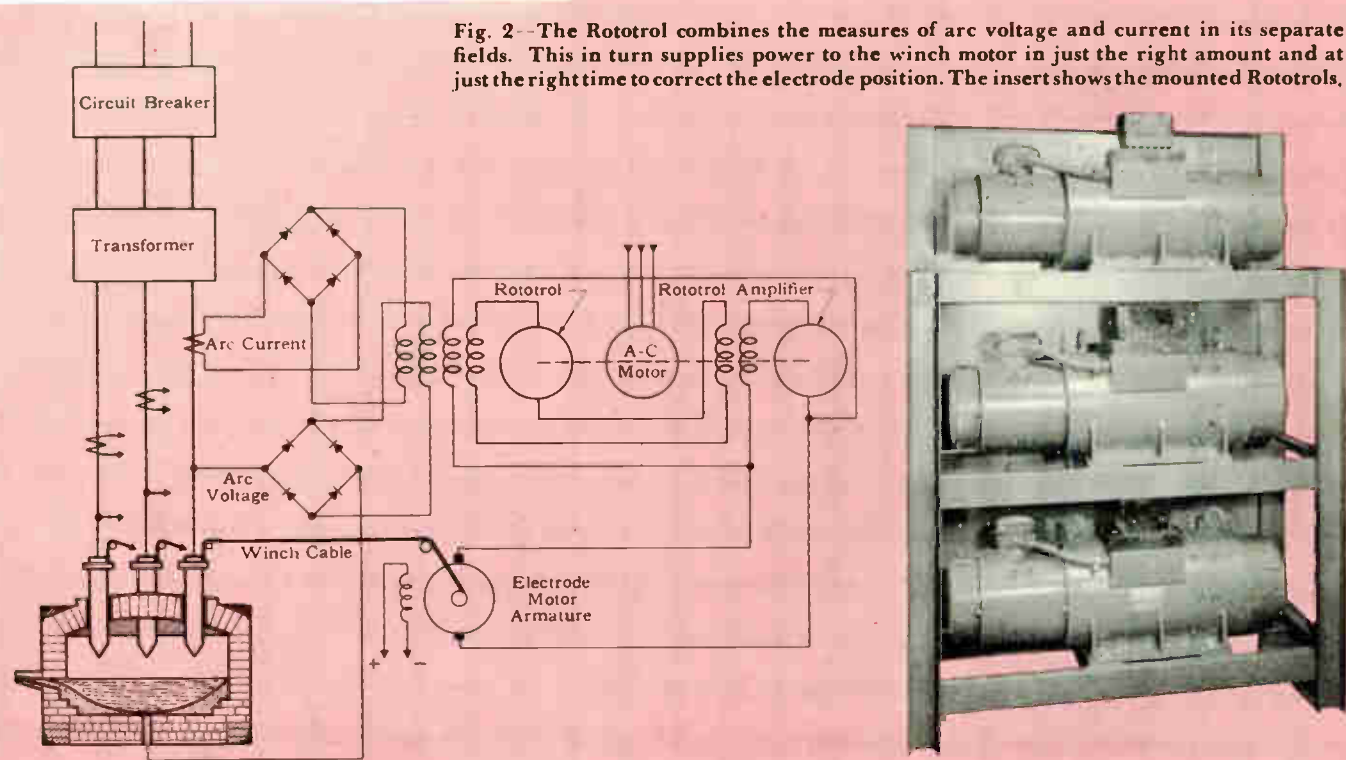


Fig. 2—The Rototrol combines the measures of arc voltage and current in its separate fields. This in turn supplies power to the winch motor in just the right amount and at just the right time to correct the electrode position. The insert shows the mounted Rototrols.

rent. The charged molecules, positive ions, bombard the incandescent electrode and cause it to emit electrons, further adding to the current-carrying capacity of the gap. In the air space through which the arc passes, an intense heat is developed which, rendering the air molecules easily ionized, gives additional assistance to the passage of current. There is also a thermionic effect by which the electrons are evaporated from the surface of the negative electrode. For these reasons an arc that has continued long enough to heat the electrodes is easily maintained. The effect is, in fact, better than cumulative, for the conductivity of the arc path, a function of arc length and arc cross-section, increases at a greater rate than a simple proportionate increase in arc current.

It is the current-carrying ability of the arc that must be corrected by circuit components. Because the voltage across the arc becomes less as the current through the arc is increased, a resistor or reactor is added to the circuit to provide stability. The reactor lends itself admirably to this application for its corrective features are particularly effective on transient conditions. The inductive reactance is so evaluated that a positive-circuit characteristic will obtain such that the voltage drop of the circuit will increase as the current is increased, in opposition to the negative tendency of the arc to lower its voltage as the current is increased.

It remains then the duty of the control element to start the arc, and then to maintain it. Both functions entail movement of the electrode. To start the arc the electrodes must be moved together to obtain a spark; to maintain the arc the electrodes must be drawn apart to provide a gap. The arc-gap spacing is subject to change caused by vaporization and melting of the electrode.

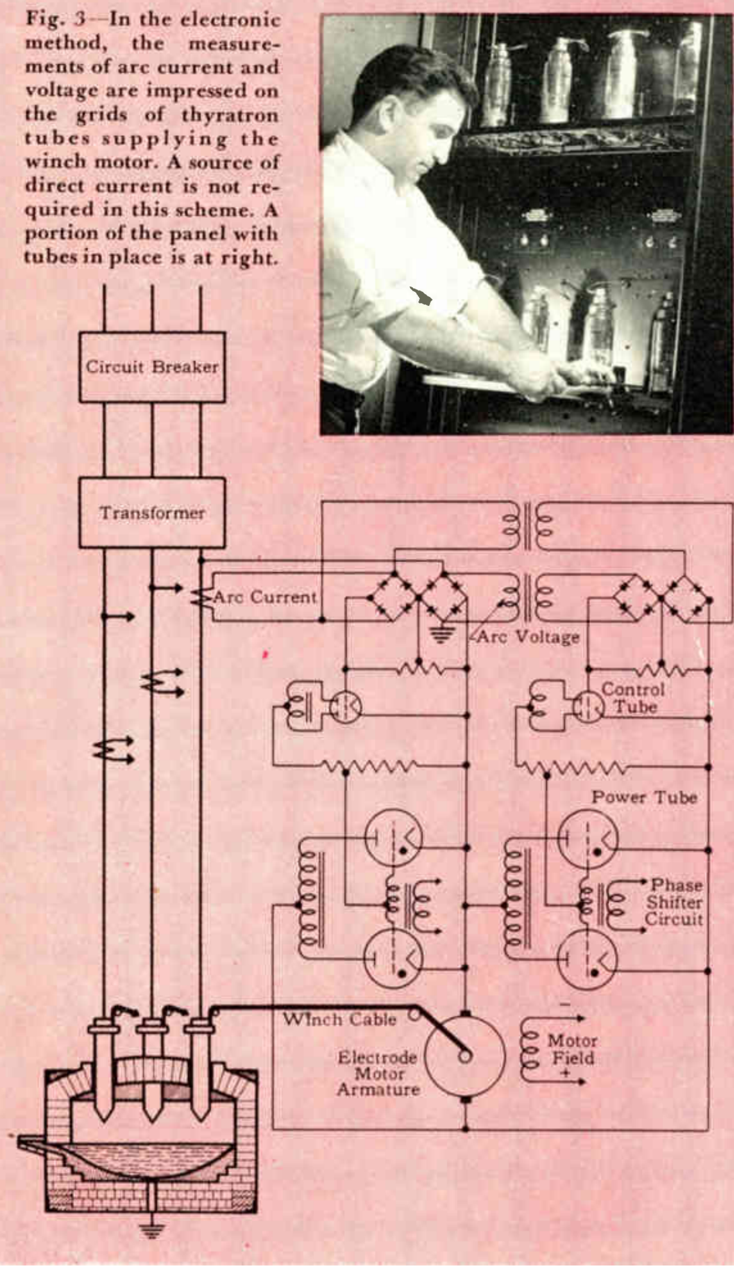


Fig. 3—In the electronic method, the measurements of arc current and voltage are impressed on the grids of thyratron tubes supplying the winch motor. A source of direct current is not required in this scheme. A portion of the panel with tubes in place is at right.

The Three Types of Regulators

One fundamental control scheme meets the requirements of arc control. The physical qualities of the arc—thickness and length, are translated into electrical quantities. Arc thickness is current. Arc length is voltage. Both quantities are measured, and, properly proportioned, affect the controls which determine the position of the electrode. This fundamental control scheme of proportioning arc current against arc voltage is implemented by three distinct types of regulating apparatus, each with particular qualities.

Balance-Beam Regulator

A mechanical-magnetic device was used first. It consists of two solenoids, one connected to measure arc current, and the other connected to measure arc voltage. Each coil operates vertical plungers attached to opposite ends of a horizontal beam. The beam is pivoted at the center. Thus the pulls exerted by both the arc current and the arc voltage are proportioned by the balance beam. Attached to the balance beam are contactors that give an electrical raise or lower signal to the electrode-positioning mechanism.

This balance-beam regulator requires special auxiliary contactors that have a heavier current-carrying capacity than those of the regulator and are used to operate the electrode-positioning motors. These are direct-current reversing motors equipped with dynamic and sometimes mechanical braking and are connected on most furnaces to the electrode through a winch and cable arrangement. The electrode motors are driven from a constant-voltage direct-current source and move the electrode to the correct position in a series of inching impulses. Inching is achieved by means of a secondary contact on the main furnace contactor that changes the proportion between current and voltage on the balance-beam regulator with each impulse signal.

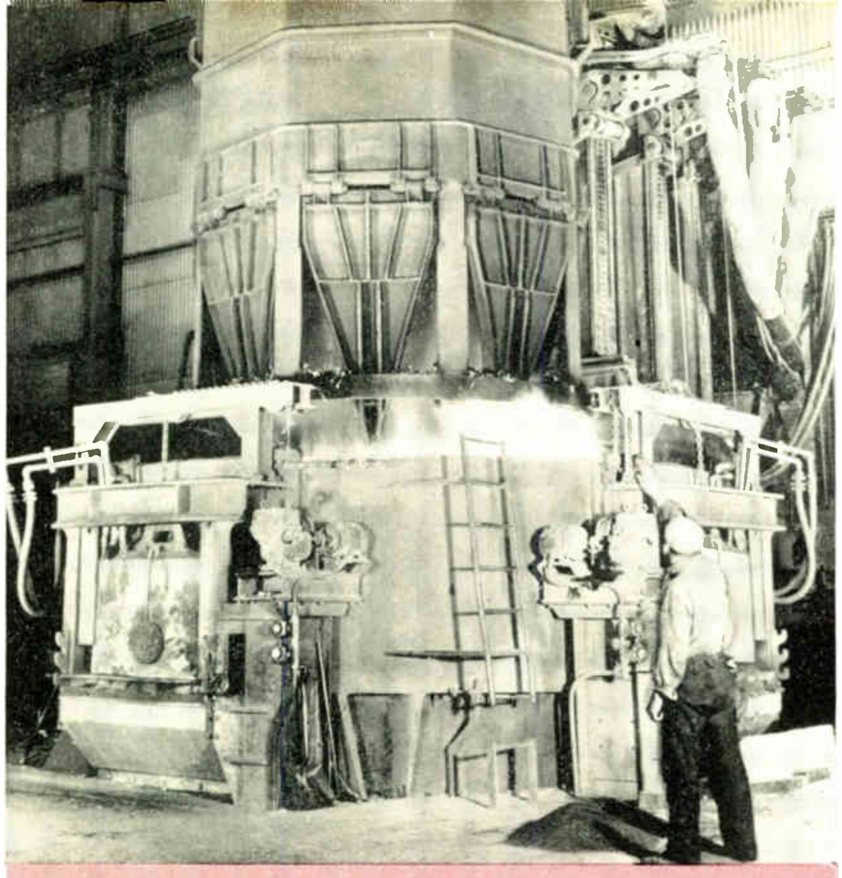
Rotating Regulator

Following the pattern of regulator evolution, the rotating-type regulator, widely used in other automatic regulating devices, has been adapted to the arc-furnace control. It provides one feature not too prominent in the balance-beam regulator and another that entirely eliminates the need for the furnace-type contactor.

The rotating regulator is essentially a direct-current generator driven by a standard squirrel-cage induction motor. The output of the regulator generator is established by varying the input to its field. The generator is provided with as many fields as are needed for a proper response to all the quantities to be measured. Because the fundamental control scheme requires a measurement of arc current and arc voltage, the generator has two intelligence fields. These fields are varied proportionately to the relative values of the arc current and the arc voltage. The balance is achieved magnetically in the generator pole pieces. The resultant flux, a combination of the properly proportioned currents indicating arc current and arc voltage, determines the generator output voltage.

This regulated voltage supplies the armature of smaller electrode motors. If the regulator controls larger electrode motors, it is necessary to use the output of the regulating generator as excitation for the field of a second generator to amplify the signal. This magnified current duplicates exactly the original and is in turn applied to the armature of the electrode motor.

The output of the rotating-regulator generator or similarly of the amplifying generator when used, has two features. First, the polarity determines which direction the electrode motor is to move, and second, the voltage level will determine how fast the electrode is to move. It is the polarity control that, by means of a balance of magnetic fluxes, eliminates the need for reversing contactors. It is the varying output voltage by means of changing the level of the resultant magnetic flux that gives to the rotating-regulator system variable-speed control, to a degree not present in the balance-beam regulator.



The roof and electrodes of this 17-foot diameter Swindell-Dressler arc furnace have been swung back to permit charging by a drop-bottom bucket.

The variable-speed control applied to the electrode motor field enables the electrode motor to respond at different rates of speed. If a severe unbalance appears between either the arc current and the arc voltage, the electrode motor will respond at a proportionately greater speed. And, as the correction is made, and the arc condition approaches balance, the speed of electrode movement decreases in accordance with the amount of the remaining unbalance. Thus a smoother electrode movement is obtained with the rotating-regulator system than is to be had by the inching movement of the balance-beam regulator.

Electronic Regulator

The third type of arc control is the electronic regulator. Practically eliminating moving parts, it embodies all the features of the preceding two types, does not require an external source of direct current, and, in addition, provides instantaneous response to the varying requirements.

Still using the fundamental control scheme, the arc current and the arc voltage are measured and rectified by dry-type rectifiers. The rectified measurements of arc current and arc voltage are connected together with polarity such that the difference in potential obtained between the two is applied to the grid of a control tube. The output of the control tube, proportioned by the arc current and voltage, is placed on the grids of two thyratron tubes. The thyratron tubes supply the direct current that operates the electrode motor. A second set of dry-type rectifiers, control tubes and thyratrons, is used for reversal of the electrode motor. A variable voltage is supplied to the electrode motor by means of phase-angle firing control of the thyratron tubes.

The end result of the regulator is to position the electrode to maintain a constant and predetermined power input to the furnace. During the years only the balance beam was available, it was used on all types of furnaces, with modification for the special needs of any particular furnace. Usually, the sensitivity and inching controls required adjustment. The balance beam has sufficient flexibility to suit itself to any furnace.

The rotating and the electronic regulators, likewise are adaptable to any type of furnace, and electrode positioning, variable-speed control. Where the electrodes are active, variable-speed control of the electrode motors has proved superior to the inching movement of the balance beam. Where the electrode activity is light, the benefits of variable-speed control are not as apparent.

The rotating and the electronic regulators differ slightly in the manner in which control of the variable-speed electrode motor is utilized. Because upsurges of electrode current require a rapid withdrawal of the electrode, it is possible with the rotating regulator to arrange for higher speed electrode pullout than electrode lowering.

All three regulators are distinguished by the number of moving elements each type uses. The balance beam analyzes its intelligence in the solenoids attached to the beam. The balance beam uses a mechanical device for each function. The rotating regulator utilizes the generator-field pole piece for analysis of intelligence and uses the generator armature for amplification of its signal, eliminating moving parts in analysis and replacing the auxiliary contactor of the balance beam with the generator armature. The electronic regulator uses a pliotron for analysis and a thyratron for amplification, thus signalling electrode position without moving parts. Against the almost complete lack of moving parts in the electronic regulator must be placed the item of tube life; while the rotating regulator and the balance beam have respectively the rotating movement of the armature and the oscillating movement of the contactor as maintenance considerations.

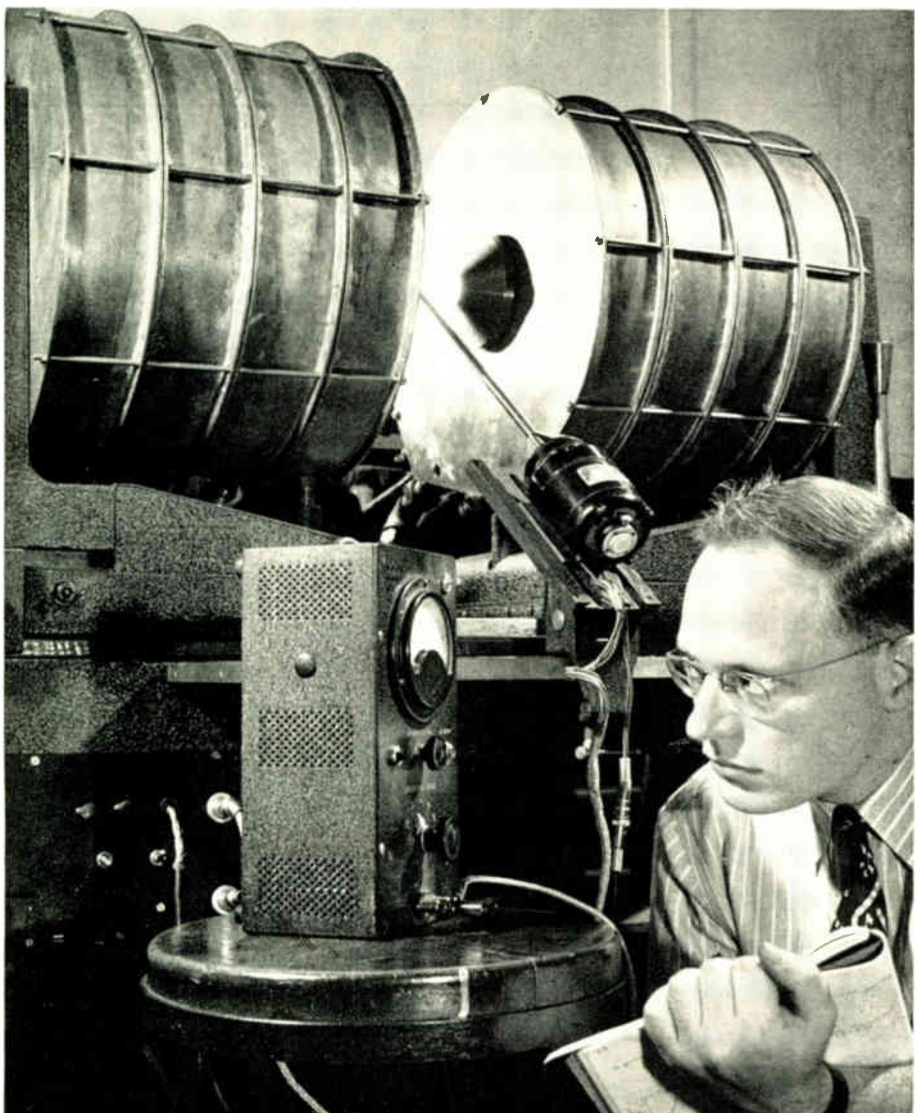
Magnets—Permanent and Strong

In the era when the Phoenicians roamed the seas, a magnet—then known as a lodestone—had but one use, to point north. In the twenty centuries since then, the mind of man has conceived a thousand and one other chores for permanent magnets and the quality requirements have kept pace with the number of applications. Recent war-important and new peacetime applications of strong permanent magnets made necessary the construction of a powerful magnetizing device. Mr. J. E. Goldman of the Westinghouse Research Laboratories has designed and built a 28 000-watt magnet expected to develop a maximum field of 40 000 gausses between the pole pieces when spaced one half inch apart. This is one of the most powerful magnets in the country for such large spacing between the poles.

The pole pieces are attracted to each other with a force of 4000 pounds. To resist this two-ton pull, the two pole assemblies are mounted on a large lathe bed, one yoke being hand set and the other motor driven. The equipment is entirely remotely controlled. The coils comprise 6400 turns of No. 8 square copper wire with glass-cloth insulation treated with temperature-resistant impregnant. At maximum load, the magnet draws 220 amperes at 150 volts.

Each coil is cooled with a circulating-oil heat exchanger to dissipate the heat.

Duplicating between four and one-half-inch pole pieces the force of a large lifting magnet several feet in diameter—such as used in handling scrap iron—the magnetic field is so strong that superpowerful permanent magnets can be made in it. It is expected that this new piece of apparatus will prove valuable in research work involving the study of the effect on the properties of metals caused by variations of intense magnetic fields.



The strength of this mammoth electromagnet is being measured with a generating flux meter by its developer, J. E. Goldman. A constant-speed motor turns a coil in the magnetic field to be measured. The speed and size of the coil being constant, the voltage generated is a direct measure of the field-flux in which the coil revolves.

More Light on Dust

To the highly versatile electron microscope has been added still another important function: the determination of the size, distribution, and shape of infinitesimal particles of dust and pollen in the air. A subject of considerable interest to the air-cleaning industries, the study of these particles has been limited by the magnifying power of the light microscope, which can give information only on particles above five microns in size (about two ten thousandths of an inch.)

But the electron microscope, with its magnification of up to 50 000 diameters, can recognize particles as small as 0.005 micron, and can determine the form of those 0.02 micron or larger. Doctors E. A. Gulbransen and R. T. Phelps of the Westinghouse Research Laboratories are making such studies on particles of dust, tobacco smoke, and pollen, collected from smoggy, rainy, and clear air.

Because the electron microscope can penetrate matter to a depth of only 0.01 to 0.05 micron, the specimens must be collected on an extremely thin film of collodion or other plastic material. This in turn is mounted on a 200-mesh stainless-steel screen ⅛ inch in diameter. Tobacco-smoke particles can be collected by holding the film and screen in a trail of smoke for a few seconds. Dust can be gathered electrostatically by making the specimen the negative electrode and a fine point the positive electrode. A large collection of dust, smoke, or pollen can either be dusted on the screen or film, or dispersed in water and a drop evaporated on the screen.

The studies Dr. Gulbransen and Dr. Phelps have made so far show the effectiveness of the electron microscope in studying air-cleaning problems. Not only can the nature of the foreign material in the air be studied, but also the efficiency of the air-cleaning process itself can be evaluated.

PERSONALITY PROFILES

Dr. E. U. Condon has been playing around with atoms for a long while. As early as 1928, only two years after receiving his Doctor of Philosophy degree from the University of California, he and Dr. R. W. Gurney developed a theory of spontaneous emission of alpha particles from radioactive materials. At that time both Dr. Condon and Dr. Gurney were at Princeton University. After leaving the University of California, Condon spent a year studying in Gottingen and Munich as a National Research Fellow. Except for brief intervals at Columbia University and the University of Minnesota he remained at Princeton until joining the staff of the Westinghouse Research Laboratories in 1937. Among other work at the Laboratories, Condon has directed the nuclear-physics activities. Since the outbreak of the war he has been engaged on several secret projects for the government, of which the most important has been in connection with the fundamental work in physics that led to the atomic bomb.

In addition to many papers on theoretical physics, Condon has collaborated in the preparation of two books, "Quantum Mechanics" and "Theory of Atomic Spectra," neither of which is recommended for bedtime reading. However, Condon writes with unusual clarity and skill, a result, no doubt, of his experience before graduation from the University of California in 1924 on the staffs of several newspapers, principally in the San Francisco area.

He is a member of Phi Beta Kappa and Sigma Xi, has served on the editorial board of *Physical Review* and is now a board member of *Journal of Chemical Physics*.

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H. G. Frostick got his engineering education the hard way (which does not mean to say there is an easy one). While working in the test department of the Consolidated Edison Company, he attended night classes at Columbia. He took up service work for Westinghouse in 1941 in the Pittsburgh district and soon found himself as familiar with all the nooks and crannies of a steel mill as a native Pittsburgher. He had a big part early in the war, when tin was so desperately short, in getting some of the electronic tin-flow lines into service. Last year he entered steel-mill application work, concentrating on furnaces and induction heating.

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R. C. Cheek is another oldtimer, as far as these pages are concerned. He discussed transformer overloads in February 1943. His current article is his second on single-sideband carrier, the first appearing last March. Cheek is a member of the central-station engineering group at Westinghouse, having graduated from Georgia Tech in 1941. During vacations from school, he first became attracted to the study of radio. He worked for a while as a radio operator on a coastwise oil tanker and later operated a broadcasting station.

He comes by his writing ability naturally through his experience as editor, while an undergraduate, of the *Georgia Tech Engineer*.

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So many people who have not had the opportunity to visit research laboratories have fixed and quite erroneous ideas as to what goes on there and the kind of men that inhabit these places. A common view of the research man is that of bearded men of large brows and austere mien and who can converse only in polysyllabic technical terms. It isn't that way, of course. Certainly *N. C. Foster* is unlike that. He is a tall, slender, well-groomed young man; in fact, his seeming youthfulness is quite striking when one recalls his record of scientific accomplishment. Foster is, in fact, a young scientist inasmuch as he was graduated from Michigan State College only eight years ago. He has furthermore endeared himself to all science writers who have discussed chemical research activities with him by his simple, easy-to-understand way of explaining complex chemical subjects coupled with great patience with the technically uninitiated. Foster has been with Westinghouse since 1939 after a two-year period in the Research Laboratory of the American Cyanamid Company working on new chemicals, principally acids. In the Westinghouse Research Laboratories Foster has specialized in the fields of resins for electrical insulations. Whatever else he may achieve his name will go down in scientific history for the class of solventless, moisture-resisting, thermosetting resins that bear the name of their discoverer—Fosterite.

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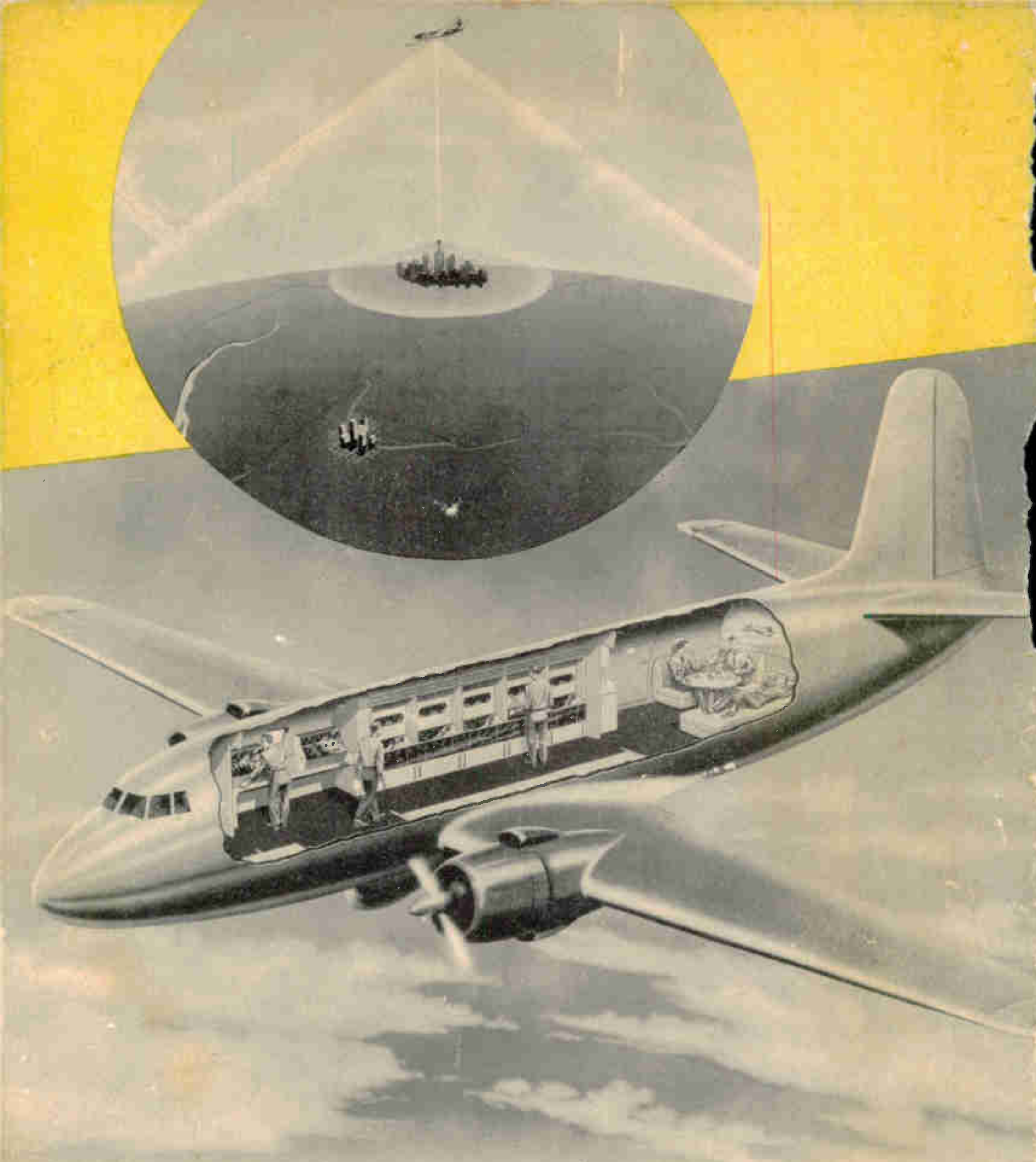
Continuing the variety of professions represented by our authors in this issue—a renowned physicist, a research chemist, a mechanical engineer, an electrical engineer—we now introduce a chemical engineer, *E. L. Schulman*. He is a Minnesotan and a graduate of the University of Minneapolis. Twice in fact. His B.S. was achieved in 1934, to which he added an M.S. in the same field in 1938. Schulman clearly liked Minneapolis and the University, for he stayed on for a couple of years to work on a project for the utilization of peat moss, a project he sadly acknowledges was not blessed with success. Schulman took the Westinghouse Student Course in 1941 and headed straight for the Chemical Laboratory and then to the Materials Engineering Department, where he has since been occupied with helping bring to practical fruit several materials such as coronox (an anti-corona agent), high-voltage insulations, and mica. His work with the Fosterites began where Research Chemist Foster left off—the establishment of a pilot plant for its commercial manufacture.



Skyhooks for Television

A system of high-flying airplanes to act as television broadcasting and repeater stations, called Stratovision, promises to simplify greatly many of the problems besetting practical operation of television. (See p.162)